

**An Investigation of Recycled Materials to Attenuate Hydrogen Sulfide from
the Beneficial use of Construction and Demolition (C&D) Waste
Fines/Residuals at a Landfill**

A Supplemental Environmental Project (SEP) prepared for:
Waste Management of Massachusetts
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1.0 Introduction

Although recycling of C&D waste is being heavily encouraged by states and regulators, a recent health issue related to the use of C&D waste, impacted the economic situation of the industry and markets for recycled C&D waste in New England. When C&D waste is processed for recycling, products including C&D waste fines and residuals are produced. Use of C&D waste fines include daily cover at operating landfills and the fines and residuals as a grading and shaping material at landfills undergoing cover construction. Since C&D waste contains gypsum drywall, C&D waste fines and residuals may include small pieces of gypsum drywall ($\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$). In reducing and anaerobic environments, sulfate reducing bacteria reduce sulfate to hydrogen sulfide also creating carbon dioxide. The rate at which hydrogen sulfide is generated by sulfate reducing bacteria depends on the amount of organic matter, concentration of dissolved oxygen in the leaching solution, the temperature, and the pH. Emissions of hydrogen sulfide are a nuisance and can be a health hazard.

There are various methods that can promote recycling of C&D waste and the state of Massachusetts has recently passed a regulation banning landfill disposal of unprocessed C&D waste (concrete, asphalt, brick, wood and metal). To make a cleaner product, construction waste can be source separated by the industry (builders and contractors). From an engineering standpoint, this has provided a product which may be more easily recycled; however in most situations the economic incentives do not exist for this to occur without a policy change (Yost and Halstead, 1994; IRG, 2001; SWMCB, 2002). Other problems exist in that demolition waste, specifically demolition drywall may contain contaminants such as lead-based paint. Both these issues make management of source separated demolition waste (e.g., drywall) difficult. Because of the economic and environmental issues associated with complete drywall removal from the mixed C&D waste stream, other attenuation measures, such as the one proposed to be examined in this project are being investigated.

Previous research has been conducted on attenuation methods including utilizing fullers earth (Landfill Oder-EndTM), bacteria, and changes in pH. However, this research explored the possibility of attenuating hydrogen sulfide generation from C&D waste fines by utilizing recycled materials. Several types of materials, including crushed concrete, wood ash, coal ash, and compost have been shown to attenuate a gas stream of hydrogen sulfide once it is extracted from the landfill (Lin et al., 2001, Sylvain, et al., 2005, Townsend et al., 2005, Xu, 2005). Although compost may attenuate hydrogen sulfide as a top attenuation layer, it may not be as applicable internally in a landfill setting. The other materials can act as sorbents (e.g., wood ash, coal ash, crushed concrete) for hydrogen sulfide. Although these types of materials have attenuated gas emissions after it is removed from the landfill (or on top of the landfill as in Florida), no tests have been conducted to see if the materials could potentially be mixed into C&D waste fines to attenuate hydrogen sulfide within the anaerobic landfill system itself.

The overall objectives of this research were twofold 1) to further the goals of C&D waste recycling by examining the composition and analysis of C&D waste fines over time and

2) to better understand the mechanisms of hydrogen sulfide generation in a landfill setting to evaluate the use of recycled materials for attenuation.

More specifically, the following steps were taken to achieve these objectives:

1. C&D waste fines characterization data (sulfate concentrations) were collected and compiled from Waste Management of Massachusetts (WMMA).
2. The sulfate concentration of C&D waste fines and residuals were determined in the laboratory at the University of New Hampshire (UNH) using an alternative extraction protocol for comparison purposes.
3. C&D waste fines and residuals were characterized by mechanical and hand-sorting to determine their composition.
4. Laboratory testing of recycled materials to attenuate hydrogen sulfide (ex-situ) was conducted.
5. Laboratory scale testing of hydrogen sulfide generation was conducted on blindly and randomly sampled C&D fines and residuals samples from a WMMA facility (Western Processing in Wilbraham, MA) and fines from a facility independent of WMMA, but serving Massachusetts (similar C&D waste stream).
6. Laboratory scale testing of hydrogen sulfide generation of simulated fines (to keep gypsum concentrations between columns consistent) and simulated fines with wood ash amendments (5%, 10% and 20%) and soil amendments (1:1, 2:1, and 3:1 soil:fines) was conducted.

This report documents a Supplemental Environmental Project (SEP) funded by WMMA with \$15,000 paid to the University of New Hampshire as UNH research project number 14B515, as a part of the Administrative Consent Order File# ACOP-06-BO-Z002-4-SETT set forth by the Commonwealth of Massachusetts. The scope of work for the SEP (as documented in this report) is contained in File# ACOP-06-BO-Z002-4-SETT, as Attachment B, and amended by a letter from WMMA Dated April 5, 2006. The scope of work and letter are contained in Appendix A of this report.

2.0 WMMA C&D Waste Fines Characterization

This Section of the report provides the results to satisfy Objective 1) to further the goals of C&D waste recycling by examining the composition and analysis of C&D waste fines over time. C&D waste fines characterization data (sulfate concentrations) were collected and compiled from WMMA. Secondly, the sulfate concentration of C&D waste fines and residuals were determined in the laboratory at UNH using an alternative extraction protocol for comparison purposes. Lastly, C&D waste fines and residuals were characterized by mechanical and hand-sorting to determine their composition.

C&D waste processing samples were collected from Western Processing in Wilbraham, MA on two occasions and another independent facility processing MA C&D waste. Samples locations and times were independently chosen by UNH personnel and occurred during normal operation of the facilities. The first set of samples from Western Processing were collected on February 1, 2006 and used for sorting characterization. Three 5-gallon buckets of C&D waste fines were collected from each of the fresh piles of fines and residuals being generated that day. A second round of sampling was similarly completed on May 26, 2006, which involved the collection of samples in buckets from the same locations to load the experimental columns. C&D waste fines samples from an independently chosen other facility were collected in 5-gallon buckets from the pile being generated that day by UNH personnel on June 14, 2006. Wood ash for the experiment was sent to UNH from a facility in Maine and the soil was sampled from the Cottage Street Landfill on May 26, 2006 by UNH personnel.

2.1 Sulfate Concentration in WMMA Data Submitted

C&D waste fines are required to be analyzed in Massachusetts for a number of parameters on a regular basis in accordance with beneficial use determination (BUD) permits issued by the Massachusetts Department of Environmental Protection (MA DEP). For this study, the total sulfate data of the WMMA fines/residuals collected as a part of their testing according to their BUD permit, was compiled and examined. Best management practices (BMPs) for removing drywall have been in use by WMMA. The characterization data were examined to determine if there was a trend to the sulfate content of the C&D waste fines over time.

In accordance with the BUD permit, WMMA contracts with a laboratory to determine total sulfate content in the WMMA C&D waste fines and residuals. In order to utilize EPA Method 300 (quantification of sulfate by ion chromatography), the sulfate must be in solution (the sulfate must be extracted from the solid into a liquid). The contract lab reported the method of extraction of the sulfate from the solid to the liquid involves adding 100 ml of deionized water to 10 g of sample (C&D fines or residuals) and mixing for one hour. The liquid extract is then analyzed by ion chromatography to determine the sulfate concentration (EPA Method 300). This concentration (in mg/L) is related to the solid and liquid fraction used in the procedure (10 g/100 ml) to determine the amount of total sulfate in mg/kg in the solid sample. The sulfate results provided by WMMA are plotted over time in Figure 2.1.

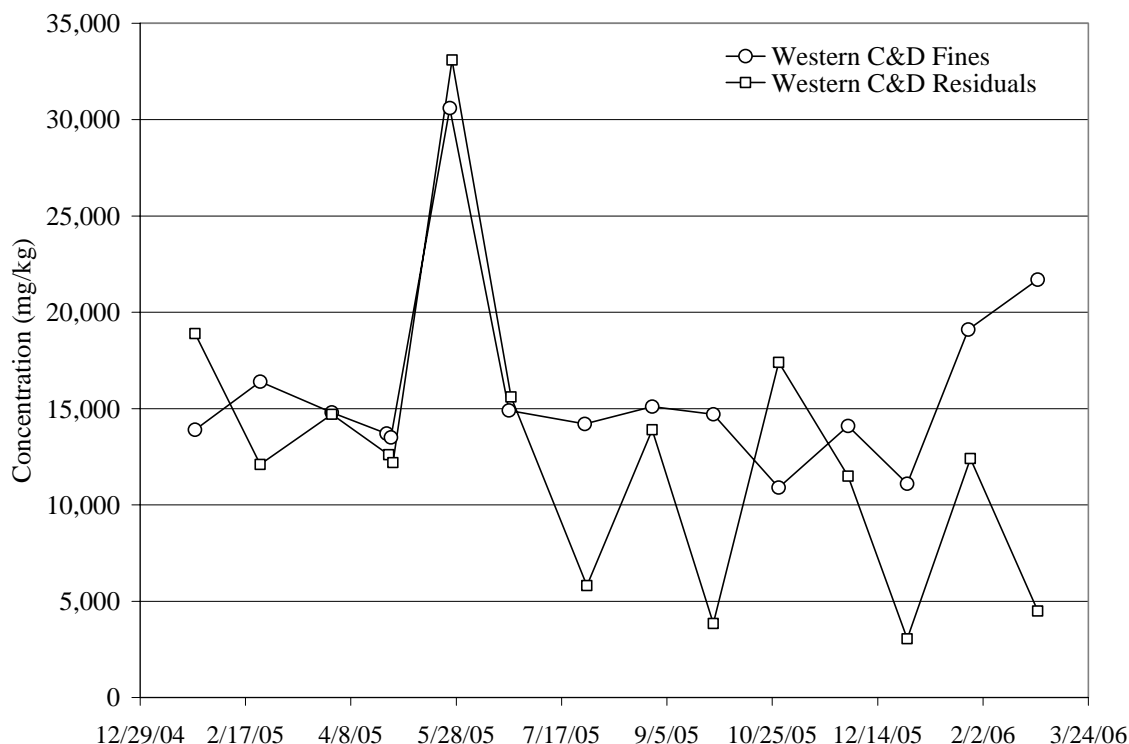


Figure 2.1 Western Processing Total Sulfate Results for C&D Waste Fines and Residuals

The sulfate concentrations range between 10,900 mg/kg and 30,600 mg/kg for C&D fines and 3,050 mg/kg and 33,100 mg/kg for C&D residuals. These concentrations can be equated to 1.1% to 3.1% and 0.3% to 3.3 % of sulfate in the samples. While the concentration in C&D residuals appeared to be decreasing, the last two sample rounds of the C&D fines saw a slight increase, although for the most part the range of concentrations are consistent over time (except for one sample of each the maximum is <2.5%) . Total sulfate concentrations can be related to total gypsum drywall concentrations by assuming the gypsum drywall is composed of 10% paper and 90% gypsum ($\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$) and utilizing the molecular weights of calcium, sulfur, oxygen, and hydrogen. The mass percentage of sulfate in the drywall is calculated to be 50.2%. resulting in gypsum drywall percentages in the C&D waste fines and residuals of 2.2% to 6.2% and 0.6% to 6.6%, respectfully.

According to the solubility of gypsum reported in Musson et al., Submitted, 5.28% of a 100 g gypsum sample could be solublized by 2 L of solution. This would mean that 2.64% gypsum could be solublized by the method currently being used by the WMMA contract laboratory. Although one sample exceeds this percentage, the laboratory stated they lowered the percentage of solid to liquid for a sample if necessary, which might be the case with this sample. However, in the current method of 10 g in 100 ml, if the sample was more than 2.64% gypsum, it could reach saturation at normal pH and temperature, incorrectly providing a result of 2.6% gypsum.

2.2 Gypsum Percentage at the UNH Laboratory

Percent gypsum was calculated for the samples collected by UNH on May 26, 2006 using the alternative daily cover (ADC) leaching protocol/standard operating procedure (SOP) developed at the University of Florida (Musson et al., Submitted). This SOP consists of the following steps:

1. 100 g of C&D waste fines or residuals sample is mixed with 2 L of deionized water in a capped plastic container.
2. The container is rotated end-over-end (mixed) for 30 minutes.
3. 1 L of the liquid is separated from the solid fraction of the sample (by filtration).
4. The conductivity of the filtrate is then measured with two resulting options:
 - a. If the conductivity measured is greater than 500 $\mu\text{S}/\text{cm}$, 10 mL of this solution is kept and mixed with, if necessary, solutions resulting from the preceding extractions (see Figure 2.2). 1 L of deionized water is then added to the mixture (that the 1 L was removed from), and steps 2 through 4 are repeated.
 - b. If the conductivity measured is lower than 500 $\mu\text{S}/\text{cm}$, 20 mL of this solution is kept and mixed, if necessary, with the solutions resulting from the preceding extractions (see Figure 2.2). The sulfate concentration of this final solution is measured by ion chromatograph.

Once the sulfate concentration of the final solution is obtained, the gypsum content or the sulfate content can be calculated with the following formulas:

$$\% \text{ Gypsum} = (n+1) * C_c * 0.001991$$

$$\% \text{ Sulfate} = (n+1) * C_c * 0.001$$

With : n = number of filtrations performed

C_c = sulfate concentration in mg/L





1st extraction	2nd extraction	3rd extraction	4th extraction
Conductivity measured : 1372 $\mu\text{S}/\text{cm}$	Conductivity measured : 836 $\mu\text{S}/\text{cm}$	Conductivity measured : 678 $\mu\text{S}/\text{cm}$	Conductivity measured : 437 $\mu\text{S}/\text{cm}$
			
10 mL	20 mL	30 mL	50 mL
10 mL of this 1st extraction is preserved	Add 10 mL of current extraction to the preceding solution	Add 10 mL of current extraction to the preceding solution	Add 20 mL of current extraction to the preceding solution (final solution)

Figure 2.2: Example of Creation of a Final Solution for the new SOP

Based upon the SOP outlined in this section, the results for samples collected from Western Processing were 2.4% gypsum for the C&D fines and 1.3% gypsum for the C&D residuals. These two percentages are in the range of data provided by WMMA and the contract laboratory presented in Section 2.1. When this new SOP was conducted on samples from the other independent facility, the C&D waste fines were found to be 14% gypsum. All extractions and sample preparations for this experiment were performed at UNH, while ion chromatograph analyses were performed by Resource Labs of Portsmouth, NH.

2.3 Sorting and Characterization of WMMA C&D Waste Fines and Residuals

The C&D fines and residuals collected on February 1, 2006 were characterized by separating the waste into components both by hand and mechanically. The samples were sorted by a series of screens and then picked through by hand into several categories given in Table 2.1. The passing fraction of C&D fines through a #4 (4.75mm opening) screen was not characterized by category, but was further separated into two fractions: the fraction remaining on a #40 (0.425mm opening) screen and the fraction passing a #40 size screen.

Moisture content analysis was conducted on three samples of each of the C&D waste fines and residuals. The moisture content of the residuals and the fines were $25\% \pm 0.3\%$ and $32\% \pm 9\%$, respectively. Table 2.1 contains the sorting characterization data of three samples of each of C&D waste fines and residuals (average and standard deviation). A total of 9.2 kg (20 lb) of residuals were sorted and 26 kg (57 lb) of fines were sorted. Figures 2.3 and 2.4 present the average composition by mass.

Table 2.1. Separation categories for Sorting of C&D Fines and Residuals

Component	C&D Waste Residuals		C&D Waste Fines	
	Average	Std Dev	Average	Std Dev
Paper	1.3%	0.2%	5.0%	2.0%
Cardboard	6.3%	1.7%	5.0%	1.0%
Plastic	2.6%	0.9%	1.3%	0.4%
Wood	64.6%	2.7%	14.3%	2.9%
Textile/insulation	3.8%	0.2%	2.4%	0.8%
Shingles	14.6%	4.0%	27.3%	3.8%
Glass/Ceramic	0.0%	0.0%	2.2%	0.2%
Metal	0.9%	0.2%	0.8%	0.6%
Concrete	1.4%	0.5%	6.3%	7.3%
Brick/stone	0%	0%	1.7%	1.3%
Gypsum	0.01%	0.01%	2.6%	2.2%
Retained on #40 Sieve	0.6%	0.1%	3.8%	0.8%
Passing #40 Sieve	3.8%	0.5%	27.1%	2.1%

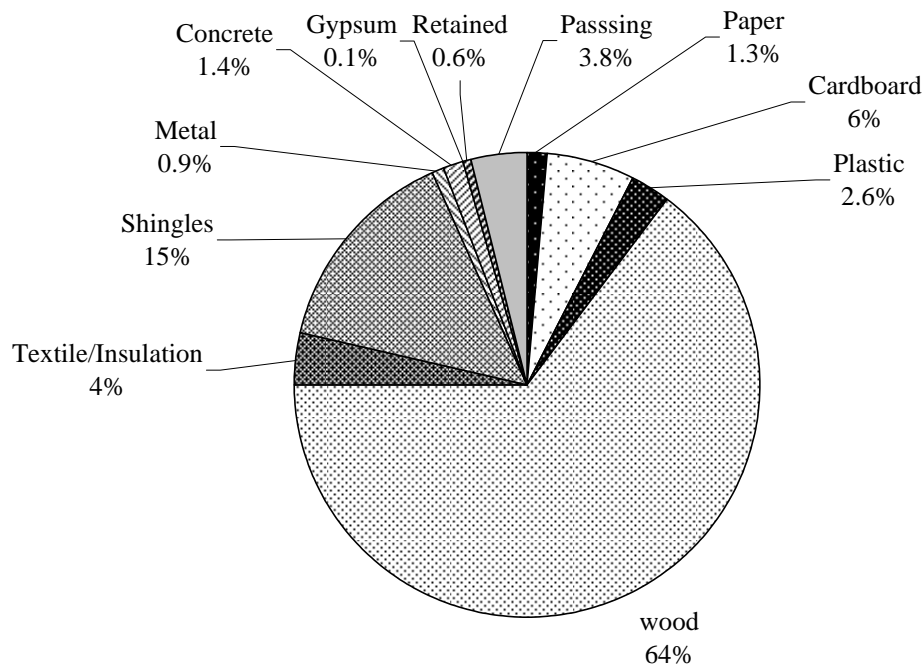


Figure 2.3. Sorting Characterization of WMMA C&D Waste Residuals

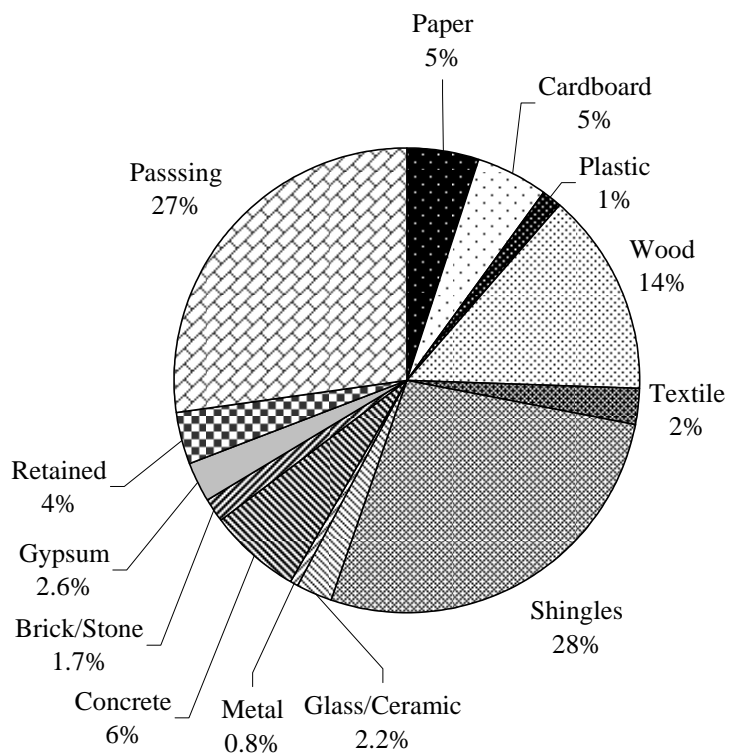


Figure 2.4. Sorting Characterization of WMMA C&D Waste Fines

The results of the sorting process show that the C&D waste residuals contain mostly wood and shingles (nearly 80%), with only approximately 4% passing and retained total fractions. The residuals contain no glass/ceramic or brick/stone. The percentage of gypsum found by hand sorting was 0.1%, however, in the extraction characterization (Section 2.2), it was found to be 1.4%. It is likely that some gypsum drywall in the waste was size-reduced through the recycling process and is contained in the passing and retained fractions. Because gypsum may be contained in the passing fraction, the ADC procedure (Musson et al., Submitted) was performed on the passing fraction (in triplicate). The percentage of gypsum in the *passing fraction only*, which compose 3.8% of the residuals was $8\% \pm 4\%$ (the elevated standard deviation is from sample results of 5.3, 5.9, and 12.7%). When the gypsum amount in the passing fraction is considered, another 0.3% of gypsum is added to the total bringing the estimate to 0.4% of gypsum in the residuals.

The C&D waste fines contained a much greater fraction of passing and retained materials than the residuals as 30% of the fines consisted of the passing and retained fractions. Shingles also made up 28% of the C&D waste fines. Wood and concrete made up the next greatest fractions at 14% and 6%. The percent gypsum found by hand separation was found to be 2.6%, similar to the 2.4% gypsum found in the extraction procedure (Section 2.2). However, this does not take into account the gypsum contained in the passing fraction, of the fines. When this fraction was analyzed with the ADC method (Musson et al., Submitted), the percentage of gypsum in the *passing fraction only* was found to be $20\% \pm 0.5\%$. This 20% gypsum content of the 27% of the passing fraction added another 5.5% gypsum resulting in an overall total of an estimated 8.1% gypsum drywall for the C&D waste fines samples.

2.4 Summary of WMMA C&D Waste Fines and Residuals Characterization

Three different methods were used to characterize the total sulfate and gypsum percentages in WMMA fines and residuals. Although the contract lab conducted total sulfate analyses, the total sulfate content is related to the total gypsum content by the method outlined in Section 2.1. A sample from a randomly chosen other facility that produces C&D waste fines from MA C&D waste was also analyzed for this project in triplicate. Table 2.2 summarizes the results of these methods for comparison.

Table 2.2. Summary of Sulfate and Gypsum Results for C&D Waste Fines/Residuals

Method	WMMA C&D Waste Fines	WMMA C&D Waste Residuals	Other Facility	Literature ¹
Contract lab total sulfate	1.1 – 3.1%	0.3 – 3.3%		
Gypsum (drywall) ²	2.2% – 6.2%	0.6 – 6.6%		
Gypsum (drywall) content-SOP method ¹	2.4%	1.4%	14%	1 – 25%
Gypsum drywall content (sorting) + SOP method ¹ on passing fraction	8.1%	0.4%		

¹Musson et al., submitted, ²Percent gypsum conversion from total sulfate assumes gypsum drywall is 90% gypsum and 10% paper

The new SOP for sulfate or gypsum characterization for C&D waste fines or residuals is a valid method because it allows for a more representative sample (larger sample size, 100 g versus 10 g) as well as the guarantee that sulfate does not reach the solubility limit biasing the sample results low. In this case, the sample results with the new method were comparable to the old method, however, this may not be the case if the gypsum content was above 2.64%. Table 2.2 also shows that the gypsum percentages of the Western Processing fines are in the lower range of the data found in the literature and data from another facility processing MA C&D waste. Although the trend of the data does not show a significant change after gypsum removal BMPs were aggressively followed at the end of 2005, it appears that WMMA already had relatively low percentages of gypsum in the C&D fines and residuals produced at Western Processing.

3.0 Laboratory Experiments of Recycled Materials for Attenuation

This Section of the report provides the results to satisfy Objective 2) To evaluate the use of recycled materials for attenuation. Laboratory testing of recycled materials to attenuate hydrogen sulfide (ex-situ) was conducted; laboratory scale testing of hydrogen sulfide generation of actual fines and residuals, and laboratory scale testing of hydrogen sulfide generation of simulated fines with various amendments was conducted.

It is important to understand that the objective of this experiment was not to determine concentrations of hydrogen sulfide released from the top of a landfill (in this case the column), but to determine them in-situ in order to compare concentrations produced between amended and unamended C&D waste fines. This objective directly relates to the methods of construction and operation of the column experiment. Lastly, this objective does not include the evaluation of the materials for any other beneficial use determination (e.g., other environmental characteristics) other than the amendments hydrogen sulfide attenuation potential. Other characteristics are to be determined in subsequent experiments and analyses.

3.1 Materials to Attenuate Hydrogen Sulfide Ex-Situ

This experiment allowed the exploration of potential amendments before designing the larger column in-situ experiment (described in Section 3.2). The experiment was designed and operated as shown in Figure 3.1, with the exception that a Jerome Meter was also used for measuring hydrogen sulfide concentrations (specifications for the Jerome Meter are in Appendix B). The mass of each potential attenuation material was recorded, as well as the volume and concentration of hydrogen sulfide passed through it. As presented in the original project scope, several materials were to be tested and these included:

- Cement Kiln Dust (CKD) – This material is a product of cement production. This material was utilized in place of crushed concrete, which has been shown to attenuate hydrogen sulfide (Xu, 2005). The weathered form of the material (from a pile allowed to weather outside the facility) was utilized.
- Taconite – Tailings from the mining industry rich in iron, which may react with the hydrogen sulfide.
- Wood Ash – Wood ash has a high percentage of carbon, which may act as a sorbent for hydrogen sulfide.
- Soil – Although it was hypothesized that soil had a lower hydrogen sulfide attenuation potential than the other materials, the fact that it is readily accessible and low in cost made it a candidate material for the study.

Figure 3.2 shows the results of the experiment. The graph shows the concentration of the hydrogen sulfide after it passes through each material versus the cumulative volume of hydrogen sulfide passed through the column. In this case, a line with lower values on the graph shows the material has a greater attenuation potential (e.g., wood ash has a higher attenuation potential than soil).

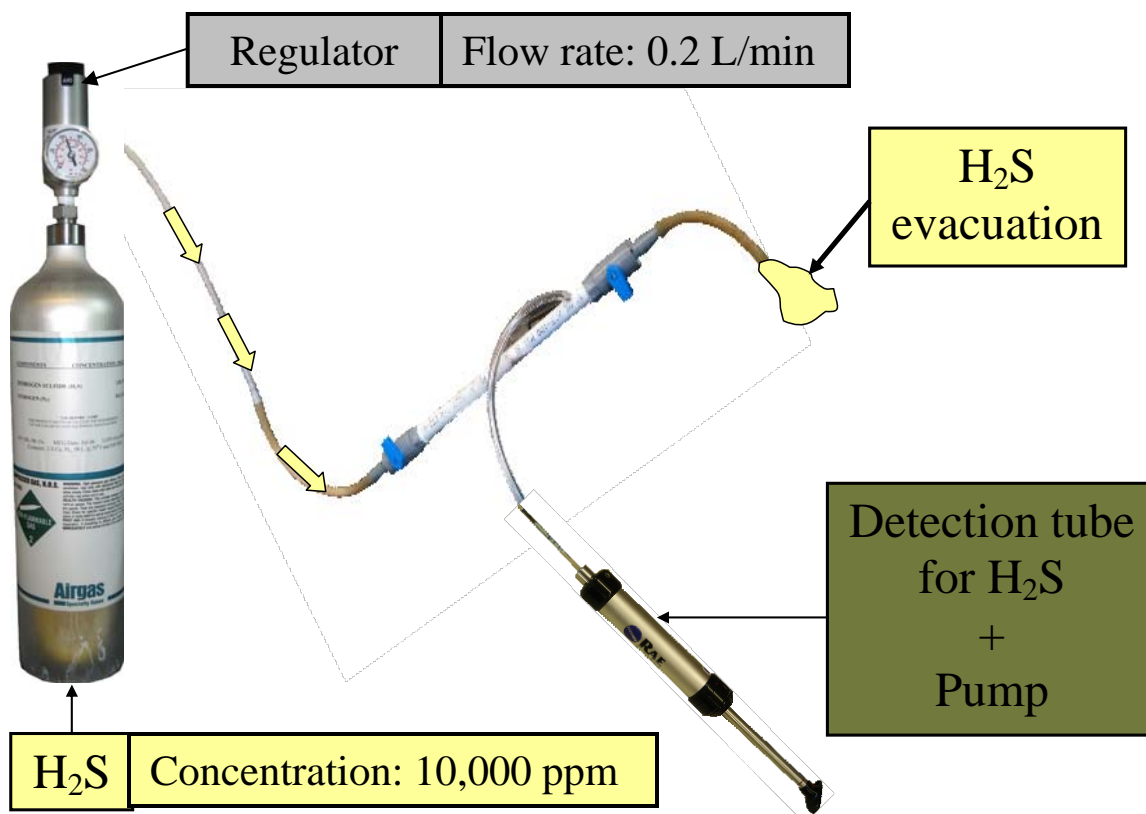


Figure 3.1. Experimental Set-up for Ex-situ Attenuation Testing

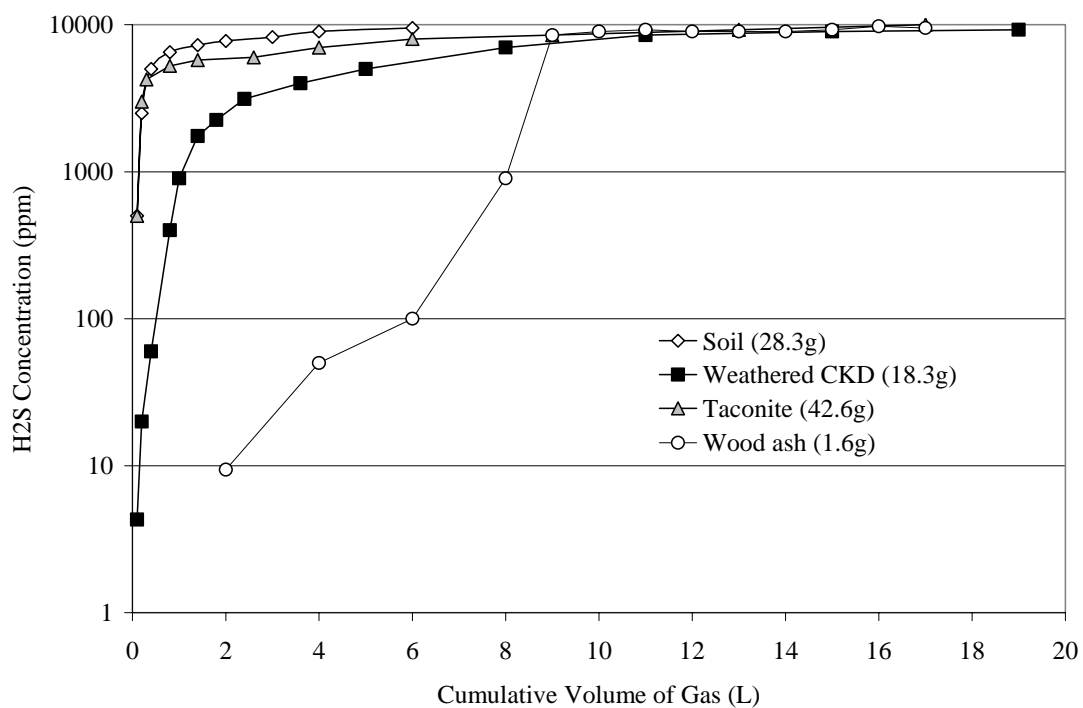


Figure 3.2. Ex-Situ Hydrogen Sulfide Attenuation potential of Various Materials

The results of this experiment show that of the materials tested, wood ash has the highest attenuation potential when hydrogen sulfide is directly passed through it. The material with the next greatest potential is CKD, followed by taconite and soil (both which have little attenuation potential in this experimental design of high hydrogen sulfide concentration and flow rate. Attenuation potential of any of these materials could change based upon many factors including gas flow rate, concentration, moisture content of the amendment, and chemistry of the amendment (e.g., pH, redox potential, etc.). The potential change in behavior of the attenuation materials in other conditions (e.g., in-situ) were reasons for conducting the next experiment.

3.2 Construction of Experimental Columns

The samples collected from Western Processing on May 26 and from the other facility on June 14 were used in this portion of the study. Since the composition of C&D waste fines can be so heterogeneous, simulated fines were generated (based upon the characteristics of the WMMA C&D waste fines found in Section 2.3), so that the quantity of gypsum loaded into the columns (with and without amendments) was known (see scope amendment letter in Appendix A). For the simulated fines, a gypsum percentage of 10% was chosen. Although this was greater than the percentage actually observed in the WMMA C&D waste fines, it was less than the other facility and in a typical range of the gypsum contents reported in the literature (See Section 2.4). The researchers wanted to ensure sufficient quantities of hydrogen sulfide would be formed to evaluate hydrogen sulfide generation and attenuation behaviors.

The amendments chosen for the larger in-situ experiment were wood ash and soil. Wood ash was chosen because in ex-situ evaluations, it showed the greatest attenuation potential of hydrogen sulfide when compared to cement kiln dust, taconite, and soil (Section 3.1). Soil was chosen because it can be mixed into fines in sufficient quantities to cause dilution of the fines as well as some attenuation. Also, similar quantities of soil can be obtained more economically than ash. A total of twelve columns were constructed and filled with the following for the experiment.

- Four columns of real samples:
 - Column 1 : WMMA C&D waste fines (Estimated at 2% Gypsum)
 - Column 2 : WMMA C&D waste fines duplicated (Estimated at 2% Gypsum)
 - Column 3 : WMMA C&D waste residuals (Estimated at 1.5% Gypsum)
 - Column 4 : Other facility C&D waste fines (Estimated at 14% Gypsum)
- Eight columns of simulated C&D waste samples with various amendments:
 - Column 5 : Simulated Fines (10% gypsum)
 - Column 6 : Simulated Fines with 5 % Wood Ash
 - Column 7 : Simulated Fines with 5 % Wood Ash duplicated
 - Column 8 : Simulated Fines with 10 % Wood Ash
 - Column 9 : Simulated Fines with 20 % Wood Ash
 - Column 10 : Simulated Fines with 50 % Soil
 - Column 11 : Simulated Fines with 66.7 % Soil
 - Column 12 : Simulated Fines with 75 % Soil

The columns were designed to be air tight and while gas was extracted, water was added. Figure 3.3 provides a schematic of the column with the prepared C&D waste fines fraction for loading. The mass calculations for each column are contained in Appendix B. The columns were loaded at 25% moisture content to initiate hydrogen sulfide production. Figure 3.4 is a photo of the finished columns.

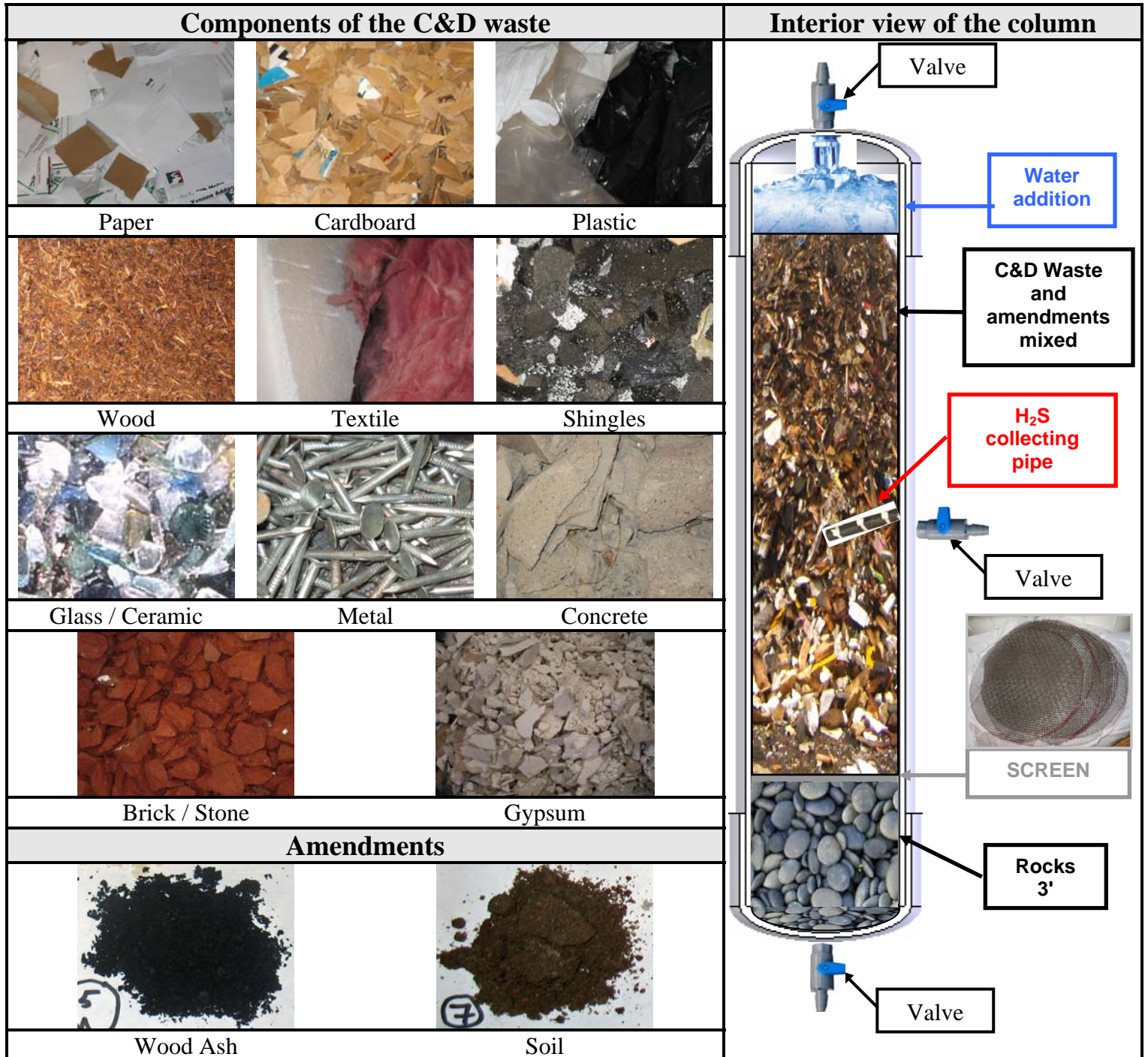


Figure 3.3 Schematic of the Materials and Experimental Columns filled with C&D Waste Fines and Amendments



Figure 3.4 Photo of the Experimental Columns filled with C&D Waste Fines and Amendments

3.2 Operation of Experimental Columns

The columns received 500 ml of reverse osmosis (RO) water weekly (with some exceptions noted in this section). 500 ml of water represented 5 days of typical rainfall in New Hampshire, accelerating the process of hydrogen sulfide generation. The process was accelerated to ensure hydrogen sulfide generation occurred within the experimental time frame. Both gas and leachate were collected from the columns weekly. Gas volume and concentration were measured and the leachate was analyzed for pH, dissolved oxygen (DO), conductivity, oxidation reduction potential (ORP), sulfate and sulfides. Appendix C contains the instrument specifications, as well as their accuracy and precision as reported by the manufacturers. This section further describes some of the monitoring methods utilized.

3.2.1 Gas Volume

Gas volume was determined by attaching a 1.5 L Tedlar bag to the top of the column and opening the top valve. Gas pressure in the column was released into the bag. The bag was submerged in a large beaker of water to determine the volume of gas (minus the volume of an empty bag). This volume measurement was found to be comparable to extracting the gas from the bag with a syringe and it allowed for a more efficient measurement, providing a safer working environment for the researcher during the experiment.

3.2.2 Hydrogen Sulfide Concentration

The gas hydrogen sulfide concentration was taken utilizing two methods from the side valve of the column. During the first two weeks of column operation a Jerome Meter was utilized for reading gas concentrations. Since the meter was rented, budget constraints did not allow the use of the meter more than 2 weeks of the experiment. For other sample events, the hydrogen sulfide concentration was measured with a hand pump and gas

sampling sticks manufactured by Rae Instruments. Although not as precise as other measurements like the Jerome meter, there were two advantages to utilizing this method. Sampling sticks are obtained for the gas concentration range encountered, allowing for full-strength sampling (gas does not need to be diluted). Also, full-strength samples could be extracted and analyzed from the columns by pumping out a known and finite sample of gas (100 ml). Both the precision and accuracy of this method was determined for various concentrations and this quality control/assurance data is contained in Appendix C.

3.2.3 Water Addition and Leachate Collection

Reverse osmosis (RO) water was added to the columns through air-tight polyethylene bags while leachate was drained for analysis. Leachate drained was directly analyzed for pH, DO, Conductivity, and ORP. Sample portions were reserved for sulfide and sulfate analyses. Sulfide analyses were completed within 24 hours and sulfate analyses were completed within 28 days (unless specified). Some technical difficulties were encountered with the initial conductivity/ORP multi-probe utilized, but a new pH/DO/ORP/Conductivity probe was obtained by day 84 and utilized for the duration of the experiment. Sulfate analyses were performed by Resource Labs of Portsmouth, NH.

The columns were operated for 174 days from June 28, 2006 through December 7, 2006 for this study. During the time span from September 8 through 29, the columns were moved out-of-doors while a negative pressure enclosure was constructed in the high-bay to house the columns in for safety reasons (high concentrations of hydrogen sulfide). During the 20 days the columns were outside, they did not receive water addition and no leachate was generated. However, gas volume and concentrations were still measured.

3.3 Experimental Column Results

Results will be presented for gas and leachate separately. In some cases, the real sample results will be grouped and in other cases, the simulated C&D waste fines with their respective amendments will be grouped to facilitate comparison.

3.3.1 Gas Volume Results

The results of the volume of gas produced by each column is provided in Table 3.1. Column 1 and Column 2 (WMMA C&D waste fines and its duplicate) perform similarly (13.8 and 9.1 L). The WMMA residuals also produce a comparable volume of gas (11.3 L). The Other Facility C&D waste fines produce a smaller volume of gas at 0.35 L. Column 6 and Column 8 (simulated fines with 5% and 10% wood ash, respectfully), have produced the largest volume of gas (16.1 and 22.6 L). The remaining columns have not produced appreciable volumes of gas (other than that taken for sampling purposes). This is not perceived as a failure of the experiment as gas was still able to be collected to obtain hydrogen sulfide concentrations (100 ml/week); however, it does mean that not enough gas pressure built up to exit at the top valve for collection. The columns did not appear to be leaking, although some leakage is possible. The gas production difference between Column 6 and 7 (simulated fines with 5% wood ash and its duplicate) do correlate with higher hydrogen sulfide concentrations. Although they were constructed the same, it appears that the population of sulfate reducing bacteria is more prolific in Column 6 than Column 7. In this size of a pilot-scale experiment there are several factors that could impact gas volume generation including water distribution or short circuiting

and oxygen intrusion from small cracks/leaks. Although Column 6 and Column 7 did not duplicate well, Column 1 and Column 2 did.

Table 3.1. Volume of Gas produced by Each Experimental Column (L)

Column	Total Gas Volume Produced (L)¹
1 – WMMA C&D Waste Fines	13.8
2 – WMMA C&D Waste Fines Duplicate	9.1
3 – WMMA C&D Waste Residuals	11.3
4 – Other Facility C&D Waste Fines	0.35
5 – Simulated Fines (10% gypsum drywall)	Negligible
6 – Simulated Fines with 5% Wood Ash	16.1
7 – Simulated Fines with 5% Wood Ash Duplicate	Negligible
8 – Simulated Fines with 10% Wood Ash	22.6
9 – Simulated Fines with 20% Wood Ash	1.2
10 – Simulated Fines with 50% Soil	Negligible
11 – Simulated Fines with 66% Soil	Negligible
12 – simulated Fines with 75% Soil	Negligible

¹Does not include the volume of gas sampled weekly for hydrogen sulfide concentration

3.3.2 Hydrogen Sulfide Concentration Results

Figure 3.5 presents the hydrogen sulfide concentrations observed in the real samples of C&D waste fines and residuals from WMMA and other facility, as well as the simulated C&D waste fines. The WMMA fines and WMMA fines duplicate behave similarly again (as they did for gas production), duplicating each other well. Based upon the percent gypsum analyses of WMMA C&D waste fines, the percent gypsum was approximately 2% in the fines and 1.5% in the residuals. The other facilities fines were measured at 14% gypsum and the simulated fines are composed of 10% gypsum. Based upon the gypsum percentages of each column, the concentrations of hydrogen sulfide exhibited by them are relative to each other (as can be seen in Figure 3.5). It appears that the percentage of gypsum in the column directly correlates to the concentration of hydrogen sulfide produced in the experiment.

Figure 3.6 presents the hydrogen sulfide concentrations observed over time for the simulated fines, two columns with 5% wood ash, a column with 10% wood ash and a column with 20% wood ash. The two 5% wood ash columns did not reproduce well (again, similar to what was observed for gas production). It appears that on the most recent sample rounds, Column 7 was increasing and Column 6 was decreasing, indicating the duplicate columns may reach the same concentration in the near future. The graph does illustrate however, that in terms of concentration attenuation, up to 20% wood ash does not attenuate in-situ hydrogen sulfide concentrations. The 20% wood ash column lagged slightly behind the others in increasing concentration, likely due to an initial elevated pH (shown in section 3.3.3). These results are relatively surprising considering wood ash attenuated hydrogen sulfide the best ex-situ, but it does not appear to work as an in-situ amendment at percentages of 20% or less. Further examination of the wood ash itself, as well as the mechanisms involved in this experiment will continue at UNH.

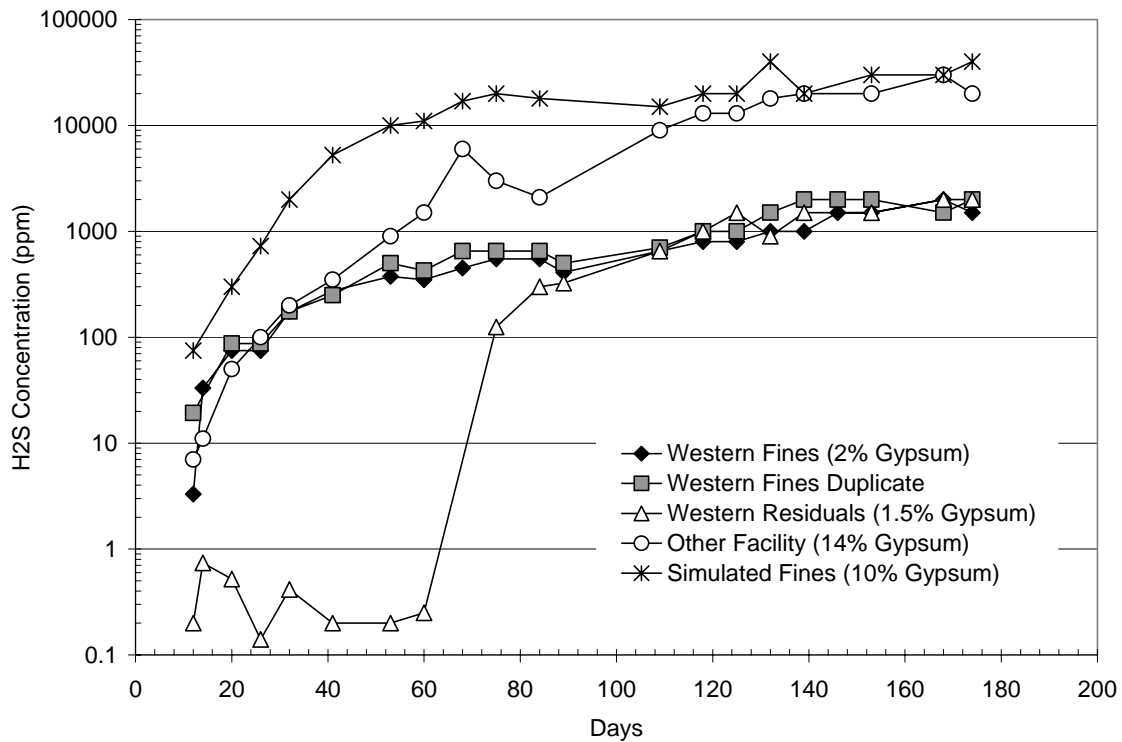


Figure 3.5. Concentrations of Hydrogen Sulfide in Real and Simulated Sample Columns

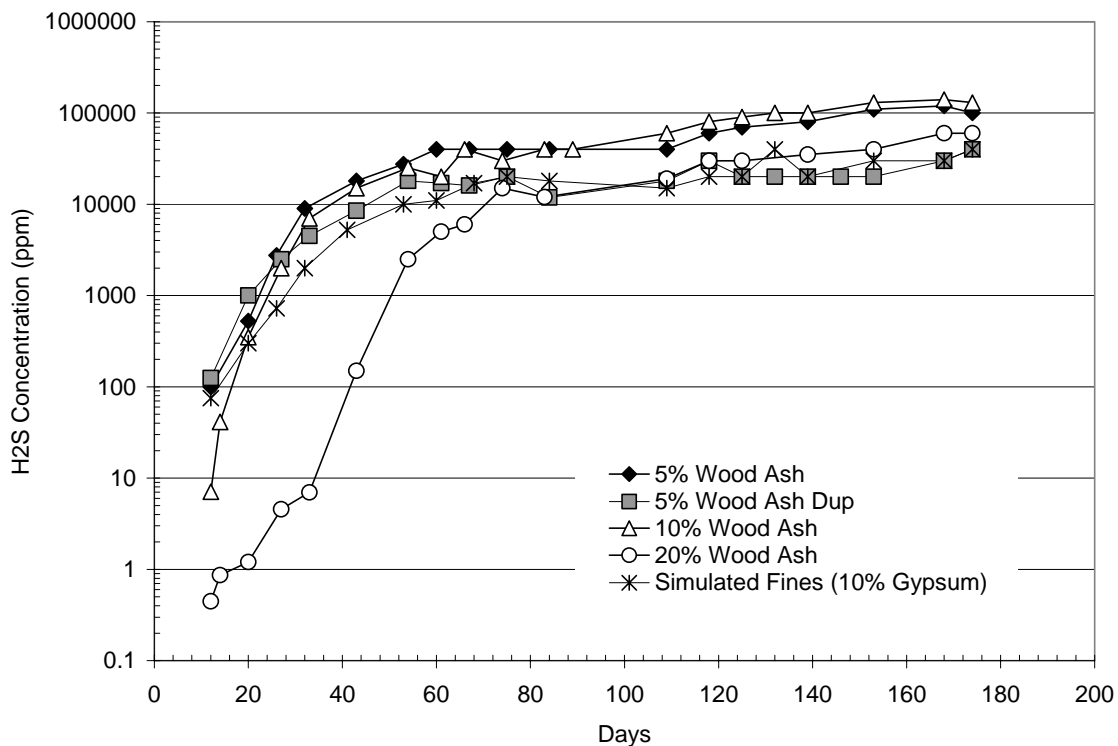


Figure 3.6. Hydrogen Sulfide Concentrations in Simulated and Experimental Columns with Wood Ash

Figure 3.7 provides the results of the simulated fines column, as well as the 1:1, 2:1 and 3:1 soil mixtures. Although the soil amendment provided the least attenuation potential ex-situ, the columns with 2:1 and 3:1 soil:fines exhibit lower concentrations of hydrogen sulfide. This is more than likely because of dilution of the fines with the large amounts of soil, but Table 3.2 also shows that the maximum concentration observed in the 3:1 soil:fines column is one-eighth of that found in the simulated fines column, even though there is one-fourth the gypsum amount. Again, the columns will continue operation at UNH to further examine the results of this experiment, however, results at this time indicate that mixing with 2:1 and 3:1 soils could result in lower hydrogen sulfide concentrations.

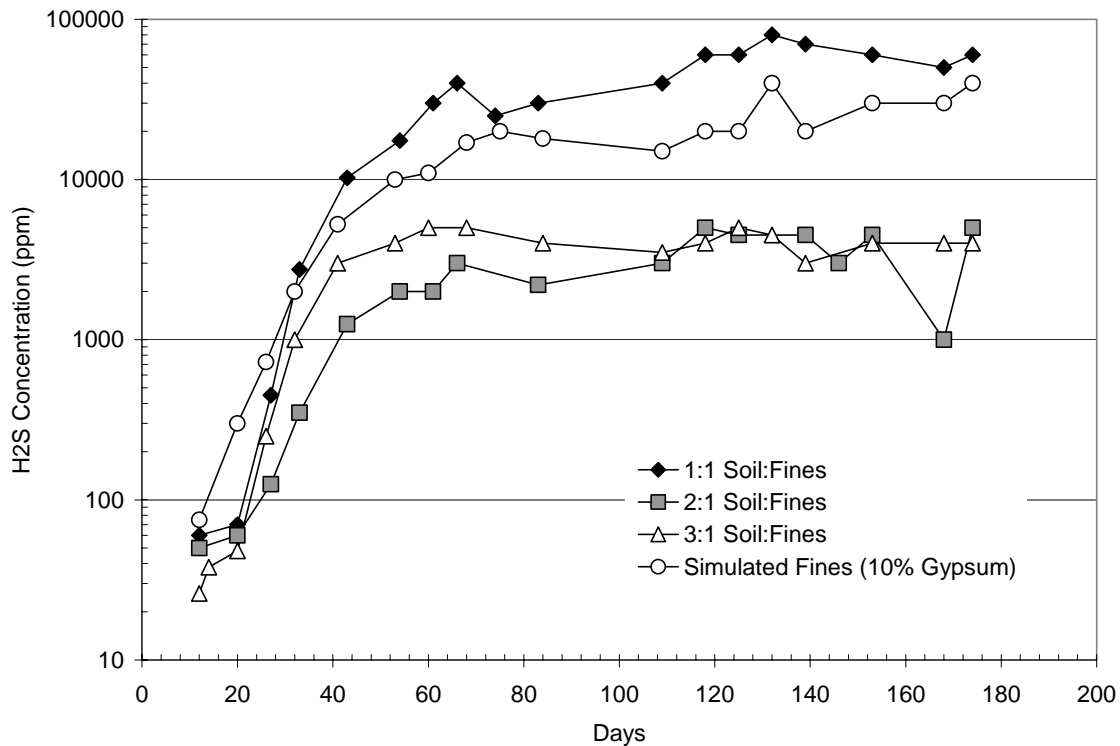


Figure 3.7. Hydrogen Sulfide Concentrations in Simulated and Experimental Columns with Soil

Table 3.2. Maximum and Minimum H₂S Concentrations for Selected Columns

Sample	% Gypsum	Min H ₂ S (ppm)	Max H ₂ S (ppm)
Western Fines	2	3.3	2000
Western Fines Dup	2	19	2000
Western Residuals	2	0.2	2000
Other Facility Fines	14	7	30,000
Simulated Fines	10	75	40,000
3:1 Soil:Simulated Fines	2.5	26	5,000

3.3.3 Leachate Results

Tables and graphs of all the leachate data obtained are presented in Appendix D. Some results are presented here for discussion purposes. One of the primary reasons leachate was characterized was to determine if the conditions in the columns were representative of a landfill setting (e.g., anaerobic and reducing environment). This environment was successfully simulated by the columns, which provided optimum conditions for sulfate reducing bacteria to thrive. For example, the pH of all the columns was in the range of 6 to 7, except for Column 9, with 20% wood ash. The pH of this column was slightly higher than the others because of the elevated pH of wood ash, although it proceeded to be neutralized relatively soon in the experiment. Figure 3.8 presents the pH of the simulated fines as well as the columns containing ash over time. The higher pH correlates with the lag time of hydrogen sulfide production shown previously in Figure 3.6.

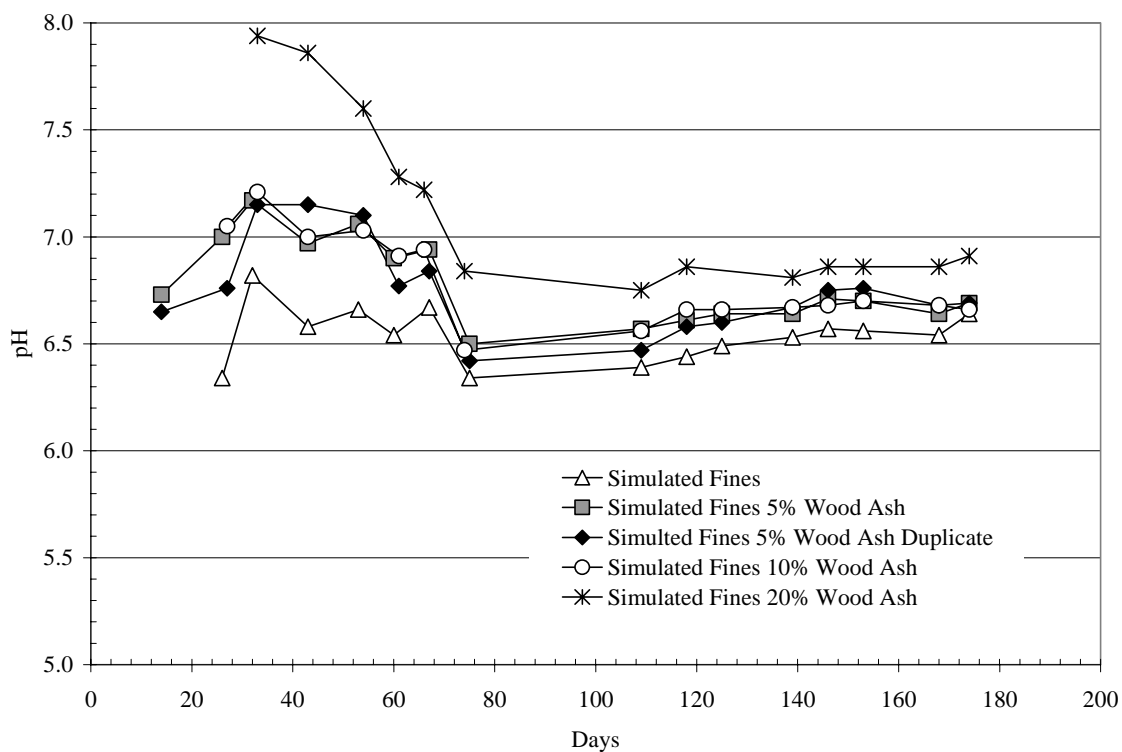


Figure 3.8. pH versus time for Simulated Fines and Wood Ash Amended Columns

Table 3.3 contains the average value of each leachate parameter monitored through the experiment. The landfill environment was simulated as can be seen by relatively low DO values and negative ORP values, indicating an anaerobic environment. The conductivity of the wood ash columns are slightly higher than the others, indicating this amendment contains ionic compounds (salts) that may be readily dissolved in solution. The sulfate and sulfide concentrations are characteristic of a hydrogen sulfide forming environment. Full data sets and graphs of data trends over time are presented in Appendix D.

Table 3.3. Mean Leachate Values for the In-situ Experimental Columns

Column	DO (mg/L)	pH	Conductivity (mS/cm)	ORP (mV)	Temp (°C)	Sulfate (mg/L)	Sulfide (mg/L)
Western Fines	0.66	6.13	9.08	-157	18.8	1392	0.81
Western Fines Dup	0.62	6.45	15.8	-216	20.8	1362	2.71
Western Residuals	1.08	6.47	3.00	-257	19.6	138	2.63
Other Facility	0.37	6.60	4.87	-325	19.7	1109	38.6
Simulated Fines (SF)	0.66	6.54	5.00	-277	20.4	498	40.7
SF w/5% Wood Ash	0.68	6.78	23.6	-367	20.3	810	210
SF w/5% Wood Ash Dup	0.84	6.75	9.29	-349	19.8	711	96.8
SF w/10% Wood Ash	1.20	6.79	34.3	-376	19.8	1351	255
SF w/20% Wood Ash	1.00	7.13	11.5	-368	19.8	2660	138.7
1:1 Soil:SF	1.07	6.64	5.57	-356	19.9	754	132
2:1 Soil:SF	1.26	6.7	4.00	-324	19.2	638	17.96
3:1 Soil:SF	1.02	6.65	3.65	-319	19.2	286	19.4

4.0 Outcomes and Recommendations

4.1 Outcomes

Although there is urgency on the part of communities and states to reduce the amount of C&D waste disposed, recycling needs to be conducted in a sustainable and environmentally sound manner. This research provided the opportunity to explore an innovative solution to an environmental, economic and health problem in the Region. Specific outcomes presented in this report and defined in the Scope of Work contained in File# ACOP-06-BO-Z002-4-SETT, as Attachment B, and amended by a letter from WMMA Dated April 5, 2006 (Appendix A of this report) include:

1. An evaluation of C&D waste fines characteristic data (including trends and statistical analysis as appropriate) – Chapter 2.0
2. Recommendations on the availability of methods to better characterize C&D waste fines for potential hydrogen sulfide generation – Chapter 2.0
3. The results of experiments evaluating recycled materials and utilizing soil and wood ash as attenuation materials for the generation of hydrogen sulfide from the use of C&D waste fines in a landfill setting – Chapter 3.0

4.2 Recommendations

Based upon the results presented in Chapter 2, it appears that the method of total sulfate determination that WMMA is utilizing characterized the C&D waste fines and residuals similarly to the new SOP extraction method (Musson et al., Submitted). However, if gypsum drywall percentages were over 2.6%, the contract laboratory extraction procedure may reach saturation unless the laboratory changed its extraction liquid-to-solid ratio. The alternative SOP by Musson et al., provides a larger sample size, which is more representative, along with the fact that potential saturation, and biased low results, can not occur.

Based upon results presented in Chapter 3, it appears that wood ash, at percentages less than 20% does not attenuate hydrogen sulfide in-situ. This chapter illustrates that just because a material attenuates hydrogen sulfide ex-situ, does not mean it will exhibit this same property in-situ. Wood ash may still attenuate hydrogen sulfide at the top of a landfill as a reactive cover, but in-situ use at 20% or less by mass is not recommended based upon these results. The soil utilized in this experiment mixed at 2:1 or 3:1 appear to attenuate hydrogen sulfide primarily by diluting the gypsum content to produce lower concentrations of hydrogen sulfide.

4.3 Limitations and Continuation of Experiment

It is important to understand that the objective of this experiment was not to determine concentrations of hydrogen sulfide released from the top of a landfill (in this case the column), but to determine concentrations in-situ in order to compare them between amended and unamended C&D waste fines. Secondly, this study does not include the evaluation of the materials for any other beneficial use determination (e.g., other environmental characteristics) other than the material's hydrogen sulfide attenuation

potential. Other characteristics (e.g., metal and mineral content) should be determined in subsequent experiments and analyses.

This experiment will continue with funding from the UNH. The Columns will be operated for one year or until hydrogen sulfide concentrations decline. Further analyses of the wood ash and soil will commence, including mineral and total metal analyses. Once the column experiment is complete, the column will be dismantled and the wood ash and soil will be analyzed for various parameters including sulfur/sulfate content, mineral and total metal composition.

5.0 References

Innovative Recycling Grants (IRG) (2001) for Okaloosa, Citrus, Putnum Counties and the New River Solid Waste Association, "Recycling of Discarded Gypsum Drywall in Florida", a report submitted to the Florida Department of Environmental Protection, prepared by the University of Florida Department of Environmental Engineering Services.

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Appendix A. Scope of Work and Change Letter

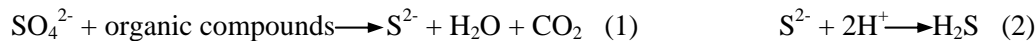
An Investigation of Recycled Materials to Attenuate Hydrogen Sulfide from the Beneficial use of Construction and Demolition (C&D) Debris Fines at a Landfill

A Supplemental Environmental Project (SEP) proposed by:
Waste Management of Massachusetts
Cottage Street Landfill Closure Project

Submitted by:
Jenna Jambeck
Environmental Research Group
Department of Civil Engineering
University of New Hampshire

1.0 Introduction

Although recycling of C&D debris is being heavily encouraged by states and regulators, a recent health issue has resulted from beneficially used C&D debris, impacting the economic situation of the industry and markets for recycled C&D debris. When C&D debris is processed for recycling, products including C&D debris fines and residuals are produced. Beneficial use of C&D debris fines include daily cover at operating landfills and the fines and residuals as grading fill for closed landfills. Since C&D debris contains a large portion of gypsum drywall, C&D debris fines and residuals may include small pieces of gypsum drywall ($\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$). In reducing and anaerobic environments, sulfate reducing bacteria thrive on the sulfate created from the dissolution of gypsum drywall (Yang, 2000). Sulfate reducing bacteria create carbon dioxide and also reduce sulfate to hydrogen sulfide by the following equations (Bitton, 1994):



The rate at which hydrogen sulfide is generated by sulfate reducing bacteria depends on the amount of organic matter, concentration of dissolved oxygen in the leaching solution, the temperature, and the pH. The emissions of hydrogen sulfide are both a health hazard and a nuisance.

There are various methods that can promote recycling of C&D debris. Construction debris can be source separated by the industry (builders and contractors). From an engineering standpoint, this has provided a cleaner product which may be more easily recycled, however economic incentives currently do not exist for this to occur without a policy change (Yost and Halstead, 1994; IRG, 2001; SWMCB, 2002). Other problems exist in that demolition debris, specifically demolition drywall may contain contaminants such as asbestos from joint compound or lead-based paint. Both these economic and environmental issues make management of source separated demolition debris (e.g., drywall) difficult. Because of the economic and environmental issues associated with complete drywall removal from the mixed C&D debris waste stream, other attenuation measures, such as the one proposed to be examined in this project will be should be investigated.

Previous research has been conducted on attenuation methods including utilizing fullers earth (Landfill Oder-EndTM), bacteria, and changes in pH. However, this proposed research is novel in that it will explore

the possibility of attenuating the hydrogen sulfide generation from C&D debris fines by utilizing recycled materials. Several types of materials, including crushed concrete, wood ash, coal ash, and compost have been shown to attenuate a gas stream of hydrogen sulfide once it is extracted from the landfill (Lin et al., 2001, Sylvain, et al., 2005). Although compost may attenuate hydrogen sulfide as a top attenuation layer, it operates more effectively in aerobic conditions, so would not be applicable internally in a landfill setting. The other materials can act as sorbents (e.g., wood ash, coal ash, MSW ash, crushed concrete) for hydrogen sulfide. Although these types of materials have attenuated gas emissions after it is removed from the landfill (or on top of the landfill as in Florida), no tests have been conducted to see if the materials could potentially be mixed into C&D debris fines to attenuate hydrogen sulfide within the anaerobic landfill system itself.

3.0 Objectives and Methods

The overall objectives of this research are twofold 1) to further the goals of C&D debris recycling by examining the composition and analysis of C&D debris fines over time and 2) to better understand the mechanisms of hydrogen sulfide generation in a landfill setting to evaluate the use of recycled materials for attenuation.

More specifically, the following steps will be taken:

7. C&D debris fines characterization data (physical properties and sulfate concentration) will be collected and compiled from WMMA.

C&D debris fines are required to be analyzed in Massachusetts for a number of parameters on a regular basis. This data will be compiled from WMMA to examine overall characteristics and trends. Best management practices for removing drywall have been introduced. The characterization data will be examined to determine if the C&D debris fines changed as a result of these BMPs. The composition of C&D debris fines will also be examined to determine if a more representative and effective method of characterization can be used (better evaluating the potential for hydrogen sulfide generation from the C&D debris fines).

8. Laboratory scale testing of several amendments mixed with C&D fines will provide a better understanding of the mechanisms involved in hydrogen sulfide attenuation, as well as determine the most effective amendment.

Blindly and randomly sampled C&D debris fines will be collected from WMMA C&D processors in Massachusetts. Air-tight reactors will be constructed in the lab. C&D debris fines will be placed in the reactors simulating their beneficial use application (moisture will be added). The quantity and concentration of hydrogen sulfide generated will be measured from unamended C&D debris fines and residuals as a baseline. Various realistic percentages (e.g., 5%, 10%, 20%) of the amendments coal ash, wood ash, MSW ash and crushed concrete will be mixed into the C&D debris fines and/or residuals to investigate attenuation characteristics. Attenuation mechanisms will also be explored (e.g., chemisorption, adsorption) through these experiments.

4.0 Outcomes

Although there is urgency on the part of communities and states to reduce the amount of C&D debris disposed, recycling needs to be conducted in a sustainable and environmentally sound manner. This research is an excellent opportunity to address an environmental, economic and health problem in the surrounding region. Specific outcomes will be published in a publicly available report which will include the following:

4. An evaluation of C&D debris fines characteristic data (including trends and statistical analysis as appropriate)
5. Recommendations on the availability of methods to better characterize C&D debris fines for potential hydrogen sulfide generation
6. The results of experiments utilizing wood ash, coal ash, MSW ash and crushed concrete as attenuation materials for the generation of hydrogen sulfide from the beneficial use of C&D debris fines in a landfill setting

5.0 Experience

Founded in 1987, The UNH Environmental Research Group's performs applied and fundamental environmental engineering and science research. The Environmental Research Group reached a milestone \$4.7 million in research expenditures during 2004 and conducts externally sponsored research in partnership with industry, municipalities, State and Federal agencies, and international organizations. Its 15 full and associate faculty members come from three departments (Civil Engineering, Microbiology, Chemical Engineering), reflecting the necessary interdisciplinary team approach to problem solving in today's world. The Environmental Research Group (ERG) also houses the Recycled Materials Resource Center (RMRC), which has examined the beneficial use of a myriad of recycled materials including coal ash, MSW incinerator ash, and recycled concrete. Experiments will be conducted in the Environmental Research Group labs where space, instruments, equipment and materials are available. ERG also has access to the University Instrumentation Center, which has scanning electron microscopes, transmission electron microscopes, a X-ray photoelectron spectroscope, an FTIR spectroscope, a series of X-ray diffractometers, and other equipment.

Dr. Jenna Jambeck came to UNH in August 2005. She is faculty in the Environmental Research Group (ERG) and Recycled Materials Resource Center (RMRC). She has eight years of experience in solid waste and C&D debris issues. In fall 2005 she spoke at the NH Department of Environmental Services solid waste seminar, the Solid Waste Association of North America Massachusetts chapter annual meeting, attended the drywall recycling meetings at the Massachusetts Department of Environmental Protection and the industry C&D debris processor meetings in Massachusetts. January 17, 2006, Dr. Jambeck participated in a briefing of the NH legislature on several issues, with her topic being C&D debris (HB 517). She is co-author on a paper for work she completed at the University of Florida (UF) sampling and characterizing Florida's C&D debris fines for inorganic contaminants. Also while at UF, she worked on three different Innovative Recycling Grants, examining the feasibility of drywall recycling within the state of Florida. Project partners included various counties, the New River Solid Waste Association and Landfill, residential and commercial builders, and Institute for Food and Agricultural Sciences at UF. Her work also included an evaluation of economic and industry impacts from various policy options for increasing recycling of C&D debris in Florida. She consulted with URS Corporation for the Solid Waste Management Coordinating Board in the Twin Cities metro area of Minnesota on a construction debris reduction and recycling project. This project entailed working with Pulte Homes (a large nationwide builder), the local C&D recycling operators, and county regulators. She was project manager of the "Assessment of True Impact of C&D Debris in Florida." This project examined the disposal impacts of C&D debris (both groundwater and gas emissions) and innovative techniques to mitigate them. She assisted in the development of www.shinglerecycling.org, in partnership with US EPA Region V and the Construction Materials Recycling Association. Her PhD research involved the construction of simulated Municipal Solid Waste and C&D debris landfills to assess impacts of the landfill disposal of treated wood. This research provided her with extensive experience with the complex biological and chemical reactions that occur in both the Municipal Solid Waste and C&D debris landfill environments. She is an invited speaker to the Solid Waste Sustainability Summit and Information Exchange Conference in San Francisco, CA in April 2006 and will be speaking at the Federation of New York Solid Waste Associations Solid Waste/Recycling Conference in May 2006 on C&D debris issues.

6.0 Budget and Timeline

A total of \$15,000 is requested. The project will begin on March 1 and end on December 31, 2006. This budget provides funding for labor, materials and laboratory analyses conducted at ERG. ERG will invoice WMMA and document all expenses on a monthly basis. A monthly progress report of activities performed will also be submitted. By December 31, a final report will be produced including the information as outlined above.

Attachments

References

CV

References

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Sylvain, M., F. Ducray, J. Gouello, F. Thevot, C. Renner and T. Lagier, 2005. "Evaluation of the Performances of Three Adsorbent to Limit Diffuse emission of Hydrogen Sulfide – Laboratory Tests and full Scale Tests on a Landfill," Proceedings Sardinia 2005, Tenth International waste Management and Landfill symposium, Italy, 3-7 October, 2005.

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EDUCATION

August 2000 - August 2004	PhD, Environmental Engineering Sciences University of Florida, Gainesville, Florida
January 1997 - July 1998	Master of Engineering, Environmental Engineering Sciences University of Florida, Gainesville, Florida
August 1992 - December 1996	Bachelor of Science, <i>with Honors</i> , Environmental Engineering Sciences University of Florida, Gainesville, Florida

PROFESSIONAL EMPLOYMENT

University of New Hampshire *Research Assistant Professor (August 2005 - Present)*

US EPA *ORISE Post-doc in the Office of Research and Development, National Risk Management Research Laboratory (October 2004-July 2005)*

University of Florida *Research and Teaching Assistant in the area of Solid and Hazardous Waste (2000-2004)*

University of Florida *Instructor for National Science Foundation Project "Science and Engineering Experiences for Knowledge," SEEK, (November 2001 - May 2003)*

URS Greiner Woodward Clyde *Senior Staff Engineer, Minneapolis, MN (1998-2000).*

University of Florida *Research and Teaching Assistant in the area of Solid and Hazardous Waste (1997-1998).*

RELEVANT PROJECT EXPERIENCE

UNH

Recycled Materials Resource Center: Leaching of Mine Waste Aggregates

Other

January 2005-June 2005

Utilized Municipal Solid Waste Decision Support Tool (MSW DST), a life-cycle based model that holistically evaluates integrated solid waste options, to evaluate waste management of chromated copper arsenate (CCA)-treated wood. Options evaluated included municipal solid waste landfills and waste-to-energy facilities.

January 2001 - August 2004

Researcher for CCA-treated wood projects sponsored by the Florida Center for Solid and Hazardous Waste. PhD dissertation topic was the disposal of CCA-treated wood in simulated landfills. Three landfill scenarios (with and without) CCA-treated wood were constructed as leaching columns: a wood monofill, a C&D debris landfill, and an MSW landfill. Leachate samples were collected and analyzed over a two year period. These findings were used to evaluate current practices as well as to examine proper disposal of CCA-treated wood.

January 2002 - August 2004

Project Manager for "Assessment of True Impact of C&D Debris in Florida." This project examined the disposal impacts of C&D debris and innovative techniques to mitigate them.

January 2003 - December 2003

Project Manager for "Recommended Management Practices for Removing Hazardous Building Components Prior to Demolition." This document will be used by demolition contractors to guide them through identification and proper management of hazardous materials during demolition.

July 2000 – September 2001

"On-line sorting technology for CCA-treated wood." This demonstration project demonstrated that laser induced spectroscopy could be used to separate CCA-treated wood out of the waste stream at a recycling facility.

August 2000 – January 2001

Provided writing and research for the report "Recycling of Discarded Gypsum Drywall in Florida", a joint recycling grant with Citrus, Putnam, Okaloosa, counties and the New River Solid Waste Authority. This report evaluated generation of drywall waste, markets, and policies for potential recycling of drywall in Florida (co-author on report).

October 2001 – December 2002

Minimization and reduction of toxicity of construction waste in Minnesota for the Solid Waste Management Coordinating Board (SWMCB). A pilot project was conducted to demonstrate the use of on-site grinding of C&D debris as beneficial use. The policy infrastructure and economic incentives for an operating C&D processing facility were also evaluated. This was a joint project with URS Corporation, Minneapolis, MN.

January 2001 – September 2001

Conducted a national survey of beneficial use and asbestos regulations in regard to asphalt roofing shingle recycling. Assisted Dr. Townsend in the development of a website www.shinglerecycling.org, specifically the regulatory portion and policy case study of Maine. The website was funded by U.S. EPA Region 5 and the Construction Materials Recycling Association (CMRA).

January 1997 – June 1998

Researcher for "Best Management Practices for Waste Abrasive Blasting Media"

Thesis, "Leaching characteristics and assessment of abrasive blasting waste from ship maintenance facilities and sandblasting contractor sites"

Assisted with "Characterization of Leachate from Construction and Demolition Waste," "Characterization and Reuse Options for Recovered Screened Material from Florida C&D Recycling Facilities," and "Leaching Characteristics of Asphalt Road Waste."

RECENT PROFESSIONAL ACTIVITIES

Provided Peer Review for NSF proposal (January, 2006)

Speaker at New Hampshire Department of Environmental Services Solid Waste seminar series (September, 2005)

Speaker at the Solid Waste Association of North America MA Chapter Annual Meeting (November, 2005)

Provide Peer Review for papers (4) in *Waste Management* and *Chemosphere* (2005 - present)

Presented Seminar at North Carolina State University Civil, Construction and Env. Eng. Dept. (March 2005)

REFEREED PUBLICATIONS

Submitted

Jambeck, J., Weitz, K., Townsend, T., Solo-Gabriele, H., "CCA-treated Wood Disposed in Landfills and Life-cycle Trade-Offs With Waste-to-Energy and MSW Landfill Disposal in the U.S.," *Waste Management*.

Jenna R. Jambeck and Jean M. Andino, "Solid Waste Disposal: A Classroom Demonstration of Landfill Design and Leachate Generation," *Journal of Chemical Education*.

In Press

Khan, B., Jambeck, J., Solo-Gabriele, H., Townsend, T., Cai, Y., "Release of Arsenic to the Environment from CCA-Treated Wood: Part II – Leaching and Speciation during Disposal," *Environmental Science and Technology*.

Jambeck, J., Townsend, T., Solo-Gabriele, H., "Leaching of Chromated Copper Arsenate (CCA)-treated Wood in a Simulated Monofill and Potential Impacts to Landfill Leachate," *Journal of Hazardous Materials*.

Clark, C., Jambeck, J., Townsend, T. (in press) "A Review of Construction and Demolition Debris Regulations in the US," *Critical Reviews in Environmental Science and Technology*.

Published

Townsend, T., Tolaymat, T., Leo, K., Jambeck, J. (2004). "Heavy Metals in Recovered Fines from Construction and Demolition Debris Recycling Facilities in Florida," *Science of the Total Environment*, Vol. 332, Issues 1-3, p. 1-11.

Solo-Gabriele, H., Townsend, T., Hahn, D., Moskal, T., Hosein, N., Jambeck, J., Jacobi, G, (2004). "Evaluation of XRF and LIBS Technologies for On-line Sorting of CCA-Treated Wood Waste," *Waste Management*, Vol. 24, No. 4, p. 413-424.

Jambeck (a.k.a. Carlson), J. and Townsend, T. (1998). "Management of Solid Waste from Abrasive Blasting" *American Society of Civil Engineers, Hazardous, Toxic, and Radioactive Waste Management Practice Periodical*, Vol. 2, No. 2, p. 72-77.

BOOK CHAPTER

Jambeck, J., Dubey, B., Townsend, T., Solo-Gabriele, H. (In Press). "Disposal of Preservative Treated Wood in Landfills," In *Environmental Impacts of Preservative Treated Wood*, Ed. Townsend, T. and Solo-Gabriele, H., CRC Press, Boca Raton, FL.

EIGHT (8) OTHER PUBLICATIONS AND TECHNICAL REPORTS

SEVEN (7) CONFERENCE PRESENTATIONS WITH PAPER ACCEPTANCE

ORGANIZATIONS/HONORS/SERVICE

- **Solid Waste Association of North America (SWANA)**, Member, (2000 – Present)
Waste reduction, recycling and composting technical member.
- **University of Florida**, Graduate Fellowship Awarded 2000-2004, \$17,000/yr
- **Air and Waste Management Association**, Member, (2003)
- **Delta Delta Delta**, University of Florida 1993-1996, Chapel Hill, NC Alumnae Chapter President (2005)
- **Tau Beta Pi**, Engineering Honor Society (1995-1997), Recording Secretary
- **Judge for the Florida Junior Science, Engineering and Humanities Symposium (JSEHS) speech competition**. Evaluated and critiqued 11th and 12th grade students' presentations of original research (February 2002).
- **University of Florida**, Center for Precollegiate Education and Training. Presented to attending high school teachers regarding solid waste topics.
- **7th Annual Public Interest Environmental Conference "All Eyes on Florida: Revitalizing, Restoring and Revisiting"** March 22-24, 2001, UF Law School
Panels Chair – Liaison between student panel assistants and panelists
Co-panel Director of "Translating Science into Law: Is the truth out there?"



April 5, 2006

Bob Magnusson
Waste Management of Massachusetts
4 Liberty Lane West
Hampton, NH 03842

Bob:

I am writing regarding the Supplemental Environmental Project (SEP) Cottage Street Landfill Closure Project that we are working on at the University of New Hampshire. The objective to evaluate various recycled materials for their attenuation of C&D debris fines is unchanged and will be completed. However, because of the heterogeneity in the samples of C&D debris fines/residuals, one method change has to be made. In order to ensure that all test columns contain similar C&D debris fines/residuals, the fines/residuals will be made at UNH.

The samples obtained from the two separate facilities will be characterized and the composition utilized to make the material at UNH. A consistent material between columns is needed to ensure that the attenuation material is evaluated (and that the emissions are not less just because there is less gypsum in that sample). An additional column will contain actual samples of C&D debris fines/residuals to determine the quality and quantity of emissions generated. Additionally, attenuation materials are being tested on their own (in mini-columns) to evaluate their effectiveness alone.

Again, the same objectives as outlined in the original proposal will be completed, it will just be a phased set of experiments (versus one large experiment) to ensure a proper and verifiable evaluation. If you have any questions, do not hesitate to contact me at any time.

Regards,

Jenna Jambeck

Appendix B. Mass and Density Calculations for In-Situ Column Experiment

Column N°1 : WMMA Fines						
Density : 400 kg/m ³						
Components	Percentage	Moisture content		Total Weight (g)	Weight (g)	Weight (lb)
		Initial	Final			
paper	REAL SAMPLE	12.20%	25.00%	10708	10708	23.6
cardboard						
plastic						
wood						
textile						
shingles						
glass/ceramic						
metal						
concrete						
brick/stone						
gypsum						
Passing						
Adsorbent	0.0%	0.0%			0	0.0
Additional water	/	/	/	1828	1828	4.0
Sum	/	12.20%	25.00%	12536	12536	27.6

Column N°2 : WMMA Fines Duplicated						
Density : 400 kg/m ³						
Components	Percentage	Moisture content		Total Weight (g)	Weight (g)	Weight (lb)
		Initial	Final			
paper	REAL SAMPLE	12.20%	25.00%	10708	10708	23.6
cardboard						
plastic						
wood						
textile						
shingles						
glass/ceramic						
metal						
concrete						
brick/stone						
gypsum						
Passing						
Adsorbent	0.0%	0.0%			0	0.0
Additional water	/	/	/	1828	1828	4.0
Sum	/	12.20%	25.00%	12536	12536	27.6

Column N°3 : WMMA Residuals						
Density : 160 kg/m ³						
Components	Percentage	Moisture content		Total Weight (g)	Weight (g)	Weight (lb)
		Initial	Final			
paper	REAL SAMPLE	11.90%	25.00%	4283	4283	9.4
cardboard						
plastic						
wood						
textile						
shingles						
glass/ceramic						
metal						
concrete						
brick/stone						
gypsum						
Passing						
Adsorbent	0.0%	0.0%			0	0.0
Additional water	/	/	/	748	748	1.6
Sum	/	11.90%	25.00%	5031	5031	11.1

Column N°4 : Other Facility Fines						
Density : 750 kg/m ³						
Components	Percentage	Moisture content		Total Weight (g)	Weight (g)	Weight (lb)
		Initial	Final			
paper	REAL SAMPLE	22.70%	25.00%	20078	20078	44.3
cardboard						
plastic						
wood						
textile						
shingles						
glass/ceramic						
metal						
concrete						
brick/stone						
gypsum						
Passing						
Adsorbent	0.0%	0.00%			0	0.0
Additional water	/	/	/	616	616	1.4
Sum	/	22.70%	25.00%	20693	20693	45.6

Column N°5 : Simulated fines						
Density : 330 kg/m ³						
Components	Percentage	Moisture content		Total Weight (g)	Weight (g)	Weight (lb)
		Initial	Final			
paper	4.8%	0.00%	25.00%	8834	425	0.9
cardboard	4.8%	0.00%			426	0.9
plastic	1.3%	0.00%			112	0.2
wood	13.8%	0.00%			1220	2.7
textile	2.4%	0.00%			208	0.5
shingles	26.2%	0.00%			2318	5.1
glass/ceramic	2.2%	0.00%			190	0.4
metal	0.8%	0.00%			70	0.2
concrete	6.1%	0.00%			537	1.2
brick/stone	1.6%	0.00%			142	0.3
gypsum	10.0%	0.00%			883	1.9
Passing	26.1%	27.70%			2304	5.1
Adsorbent	0.0%	0.00%			0	0.0
Additional water	/	/	/	2094	2094	5
Sum	100.0%	7.22%	25.00%	10928	10928	24.1

Column N°6 : Simulated fines with 5% Wood ash						
Density : 330 kg/m ³						
Components	Percentage	Moisture content		Total Weight (g)	Weight (g)	Weight (lb)
		Initial	Final			
paper	4.6%	0.00%	25.00%	8834	404	0.9
cardboard	4.6%	0.00%			404	0.9
plastic	1.2%	0.00%			106	0.2
wood	13.1%	0.00%			1159	2.6
textile	2.2%	0.00%			198	0.4
shingles	24.9%	0.00%			2202	4.9
glass/ceramic	2.0%	0.00%			181	0.4
metal	0.7%	0.00%			66	0.1
concrete	5.8%	0.00%			510	1.1
brick/stone	1.5%	0.00%			135	0.3
gypsum	9.5%	0.00%			839	1.9
Passing	24.8%	27.70%			2188	4.8
Adsorbent	5.0%	30.40%			442	1.0
Additional water	/	/	/	1957	1957	4.3
Sum	100.0%	8.38%	25.00%	10792	10792	23.8

Column N°7 : Simulated fines with 5% Wood ash Duplicated						
Density : 330 kg/m ³						
Components	Percentage	Moisture content		Total Weight (g)	Weight (g)	Weight (lb)
		Initial	Final			
paper	4.6%	0.00%	25.00%	8834	404	0.9
cardboard	4.6%	0.00%			404	0.9
plastic	1.2%	0.00%			106	0.2
wood	13.1%	0.00%			1159	2.6
textile	2.2%	0.00%			198	0.4
shingles	24.9%	0.00%			2202	4.9
glass/ceramic	2.0%	0.00%			181	0.4
metal	0.7%	0.00%			66	0.1
concrete	5.8%	0.00%			510	1.1
brick/stone	1.5%	0.00%			135	0.3
gypsum	9.5%	0.00%			839	1.9
Passing	24.8%	27.70%			2188	4.8
Adsorbent	5.0%	30.40%			442	1.0
Additional water	/	/	/	1957	1957	4.3
Sum	100.0%	8.38%	25.00%	10792	10792	23.8

Column N°8 : Simulated fines with 10% Wood ash						
Density : 330 kg/m ³						
Components	Percentage	Moisture content		Total Weight (g)	Weight (g)	Weight (lb)
		Initial	Final			
paper	4.3%	0.00%	25.00%	8834	383	0.8
cardboard	4.3%	0.00%			383	0.8
plastic	1.1%	0.00%			100	0.2
wood	12.4%	0.00%			1098	2.4
textile	2.1%	0.00%			187	0.4
shingles	23.6%	0.00%			2086	4.6
glass/ceramic	1.9%	0.00%			171	0.4
metal	0.7%	0.00%			63	0.1
concrete	5.5%	0.00%			483	1.1
brick/stone	1.4%	0.00%			128	0.3
gypsum	9.0%	0.00%			795	1.8
Passing	23.5%	27.70%			2073	4.6
Adsorbent	10.0%	30.40%			883	1.9
Additional water	/	/	/	1821	1821	4.0
Sum	100.0%	9.54%	25.00%	10655	10655	23.5

Column N°9 : Simulated fines with 20% Wood ash

Density : 330 kg/m ³						
Components	Percentage	Moisture content		Total Weight (g)	Weight (g)	Weight (lb)
		Initial	Final			
paper	3.9%	0.00%	25.00%	8834	340	0.8
cardboard	3.9%	0.00%			340	0.8
plastic	1.0%	0.00%			89	0.2
wood	11.0%	0.00%			976	2.2
textile	1.9%	0.00%			166	0.4
shingles	21.0%	0.00%			1854	4.1
glass/ceramic	1.7%	0.00%			152	0.3
metal	0.6%	0.00%			56	0.1
concrete	4.9%	0.00%			429	0.9
brick/stone	1.3%	0.00%			114	0.3
gypsum	8.0%	0.00%			707	1.6
Passing	20.9%	27.70%			1843	4.1
Adsorbent	20.0%	30.40%			1767	3.9
Additional water	/	/	/	1548	1548	3.4
Sum	100.0%	11.86%	25.00%	10382	10382	22.9

Column N°10 : Simulated fines with 50% Soil

Density : 650 kg/m ³						
Components	Percentage	Moisture content		Total Weight (g)	Weight (g)	Weight (lb)
		Initial	Final			
paper	2.4%	0.00%	25.00%	17401	419	0.9
cardboard	2.4%	0.00%			419	0.9
plastic	0.6%	0.00%			110	0.2
wood	6.9%	0.00%			1201	2.6
textile	1.2%	0.00%			205	0.5
shingles	13.1%	0.00%			2283	5.0
glass/ceramic	1.1%	0.00%			188	0.4
metal	0.4%	0.00%			69	0.2
concrete	3.0%	0.00%			529	1.2
brick/stone	0.8%	0.00%			140	0.3
gypsum	5.0%	0.00%			870	1.9
Passing	13.0%	27.70%			2269	5.0
Adsorbent	50.0%	11.00%			8700	19.2
Additional water	/	/	/	3686	3686	8.1
Sum	100.0%	9.11%	25.00%	21087	21087	46.5

Column N°11 : Simulated fines with 66% Soil						
Density : 680 kg/m ³						
Components	Percentage	Moisture content		Total Weight (g)	Weight (g)	Weight (lb)
		Initial	Final			
paper	1.6%	0.00%	25.00%	18204	292	0.6
cardboard	1.6%	0.00%			292	0.6
plastic	0.4%	0.00%			77	0.2
wood	4.6%	0.00%			838	1.8
textile	0.8%	0.00%			143	0.3
shingles	8.7%	0.00%			1592	3.5
glass/ceramic	0.7%	0.00%			131	0.3
metal	0.3%	0.00%			48	0.1
concrete	2.0%	0.00%			369	0.8
brick/stone	0.5%	0.00%			98	0.2
gypsum	3.3%	0.00%			607	1.3
Passing	8.7%	27.70%			1582	3.5
Adsorbent	66.7%	11.00%			12136	26.8
Additional water	/	/	/	3704	3704	8.2
Sum	100.0%	9.74%	25.00%	21907	21907	48.3

Column N°12 : Simulated fines with 75% Soil						
Density : 830 kg/m ³						
Components	Percentage	Moisture content		Total Weight (g)	Weight (g)	Weight (lb)
		Initial	Final			
paper	1.2%	0.00%	25.00%	22219	267	0.6
cardboard	1.2%	0.00%			268	0.6
plastic	0.3%	0.00%			70	0.2
wood	3.5%	0.00%			767	1.7
textile	0.6%	0.00%			131	0.3
shingles	6.6%	0.00%			1457	3.2
glass/ceramic	0.5%	0.00%			120	0.3
metal	0.2%	0.00%			44	0.1
concrete	1.5%	0.00%			338	0.7
brick/stone	0.4%	0.00%			89	0.2
gypsum	2.5%	0.00%			555	1.2
Passing	6.5%	27.70%			1448	3.2
Adsorbent	75.0%	11.00%			16665	36.7
Additional water	/	/	/	4427	4427	9.8
Sum	100.0%	10.06%	25.00%	26647	26647	58.8

Appendix C. Instrument Accuracy and Precision Data

- H₂S: Detection tubes + pump by RAE system

<u>Manuf. Reported ACCURACY</u>	
Concentration (ppm)	Accuracy
50 - 800	+/- 10 %
1000 - 20000	+/- 10 %
2 – 40%	+/- 10 %

- UNH conducted Accuracy and Precision

- Accuracy at 50 ppm (three readings) – 167% +/- 15 %
 - Accuracy at 10,000 ppm (three readings) – 107% +/- 2.5 %
 - Precision at 2000 ppm (three readings) +/- 0 %
 - Precision at 30,000 – 40,000 ppm (three readings) +/- 17 %
 - Precision at 140,000 – 160,000 ppm (three readings) +/- 8 %

- H₂S meter : Jerome® 631-X by Arizona Instrument

<u>Manuf. Reported ACCURACY JEROME METER</u>	
Concentration (ppm)	Accuracy (at mid-range)
0,001 - 0,099	+/- 0,003
0,10 - 0,99	+/- 0,03
1,0 - 9,9	+/- 0,3
10,0 - 50,0	+/- 2

- pH meter : Accumet AB15 Basic by Fisher Scientific

<u>Manuf. Reported ACCURACY pH METER</u>
+/- 0,01

- Conductivity meter : Orion 555A by Thermo Electron Corporation

<u>Manuf. Reported ACCURACY CONDUCTIVITY METER</u>	
+/- 0.5% +/- 1 digit	
<u>Manuf. Reported ACCURACY CONDUCTIVITY PROBE</u>	
Conductivity	Accuracy
≤ 150 µS	+/- 5 µS
≥ 150 µS	+/- 3 %

- Sulfide Analyzer, Spectrophotometer : DR/2000 by HACH

Manuf. Reported ACCURACY SPECTROPHOTOMETER
+/- 2 %

- DO meter : YSI 556 MPS by GENEQ

Manuf. Reported ACCURACY DO METER	
Concentration (mg/L)	Accuracy
0 - 20	+/- 2 %
20 - 50	+/- 6 %

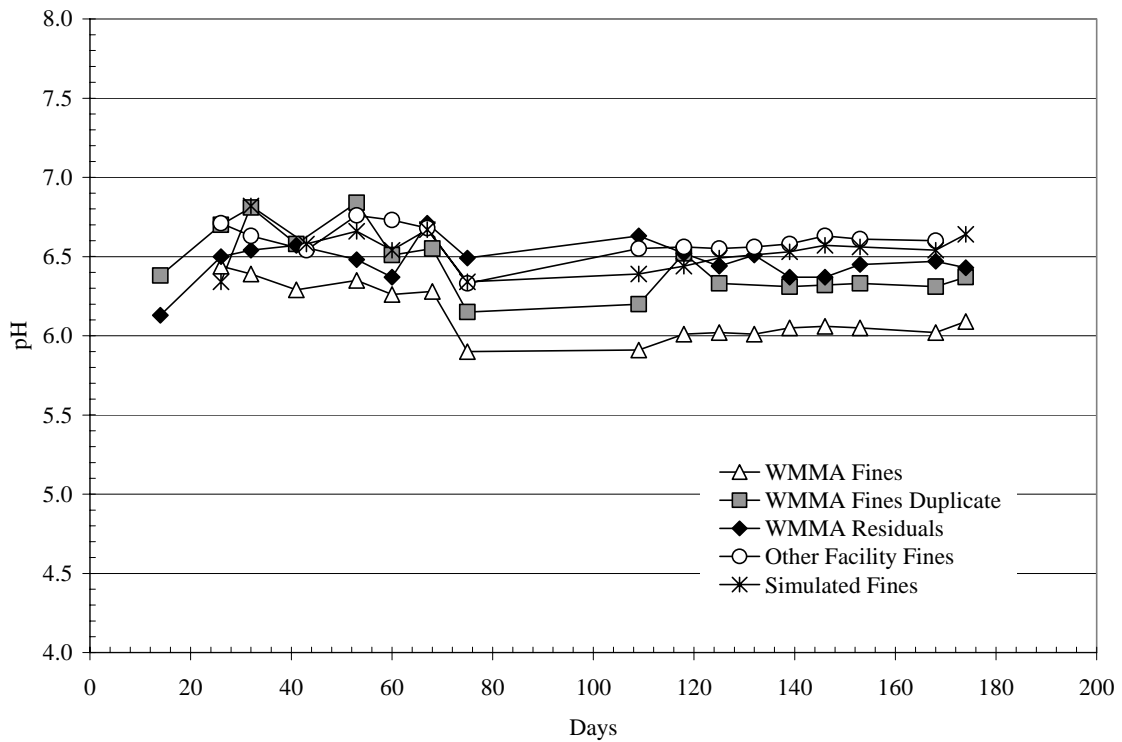
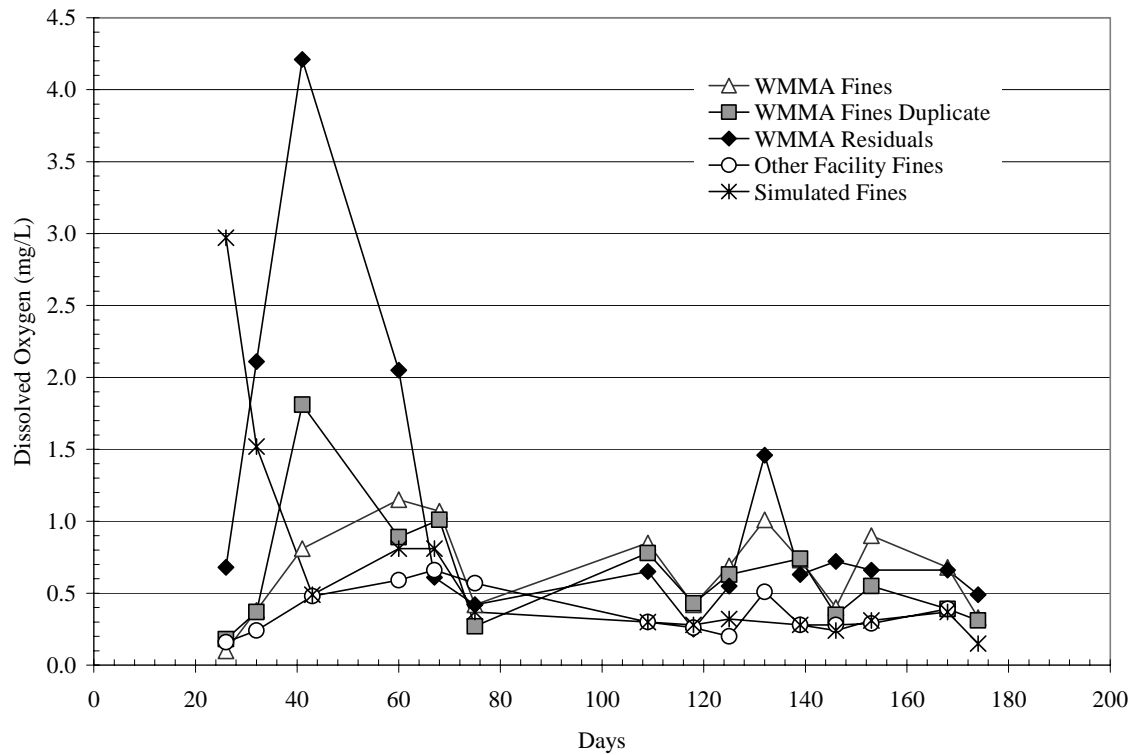
- ORP meter : Model 8100 pH/Temp./mV by VWR Scientific Products

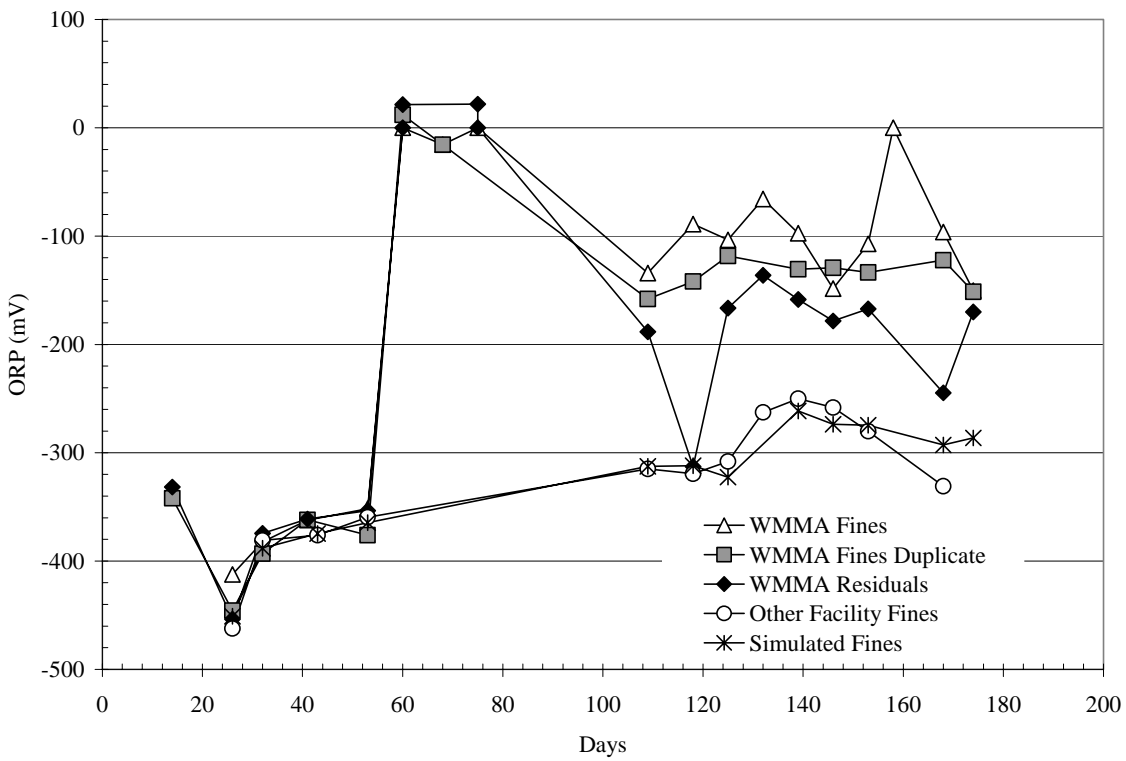
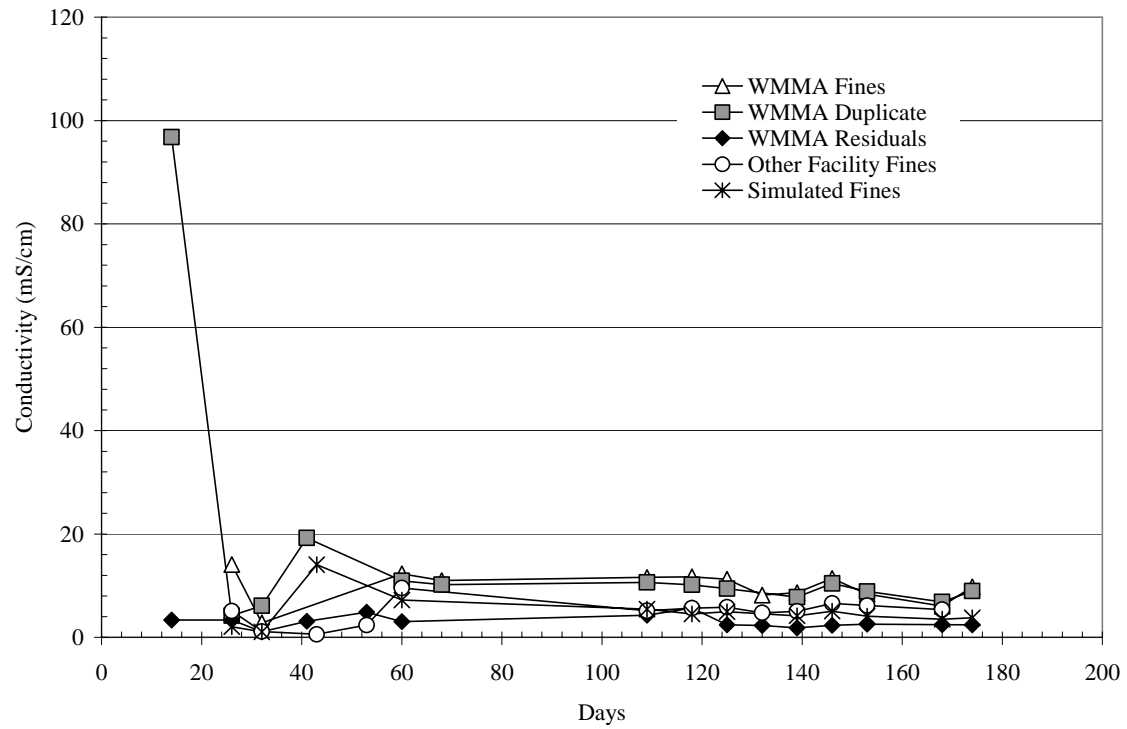
Manuf. Reported ACCURACY ORP METER
+/- 0,2 mV

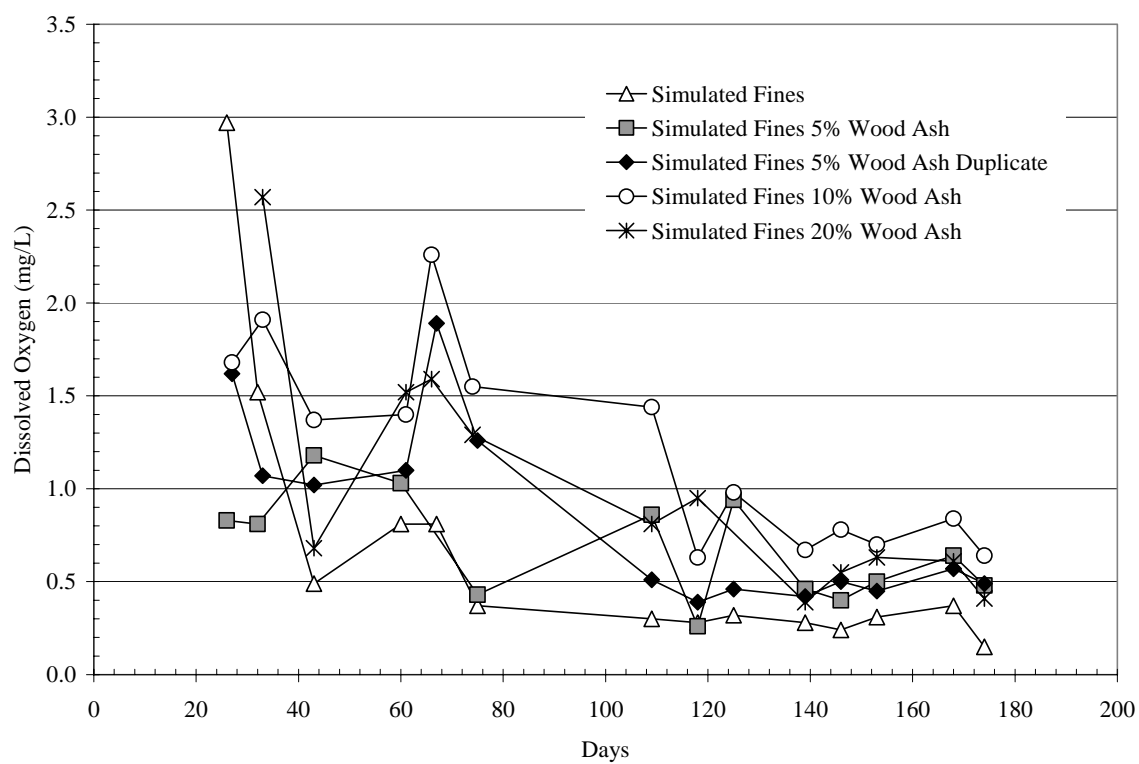
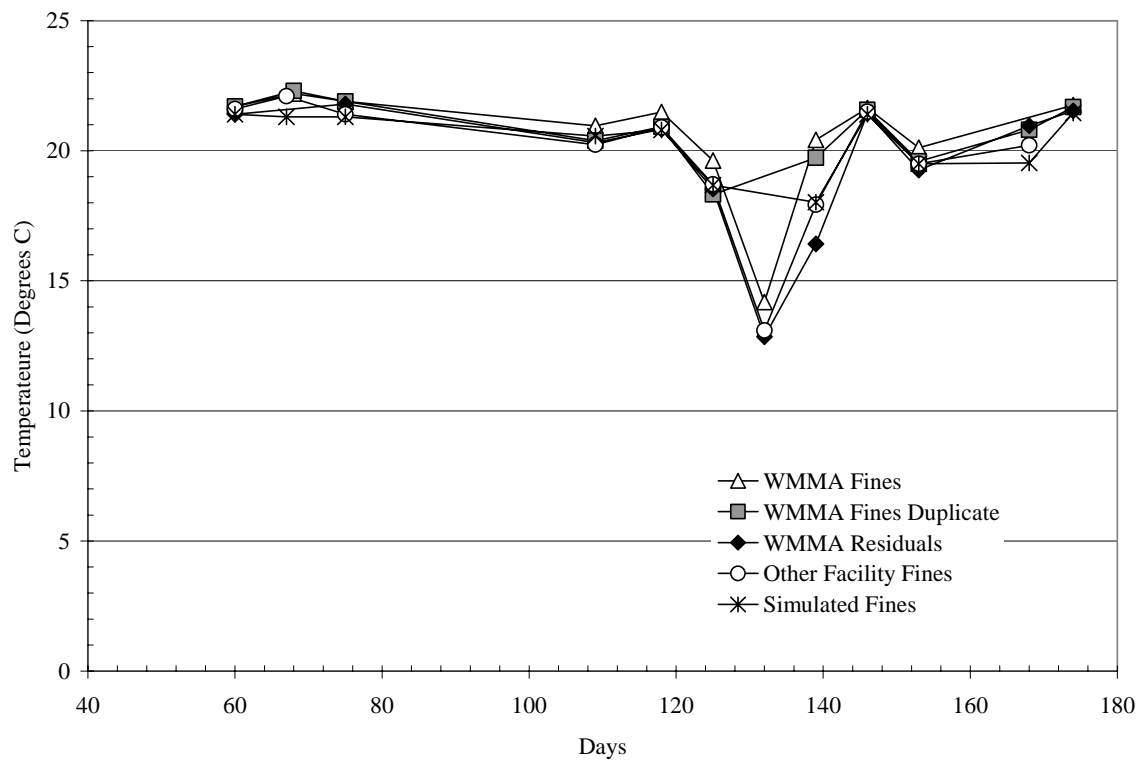
- YSI 556 Multi Probe System (Manuf. Reported)

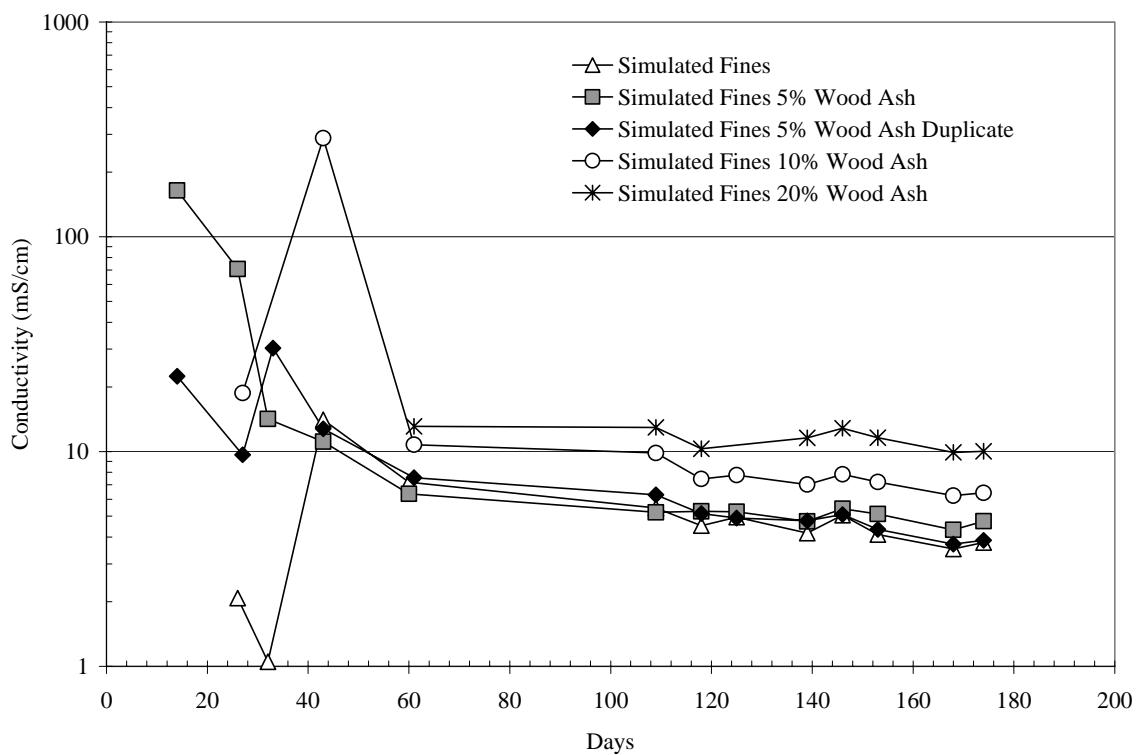
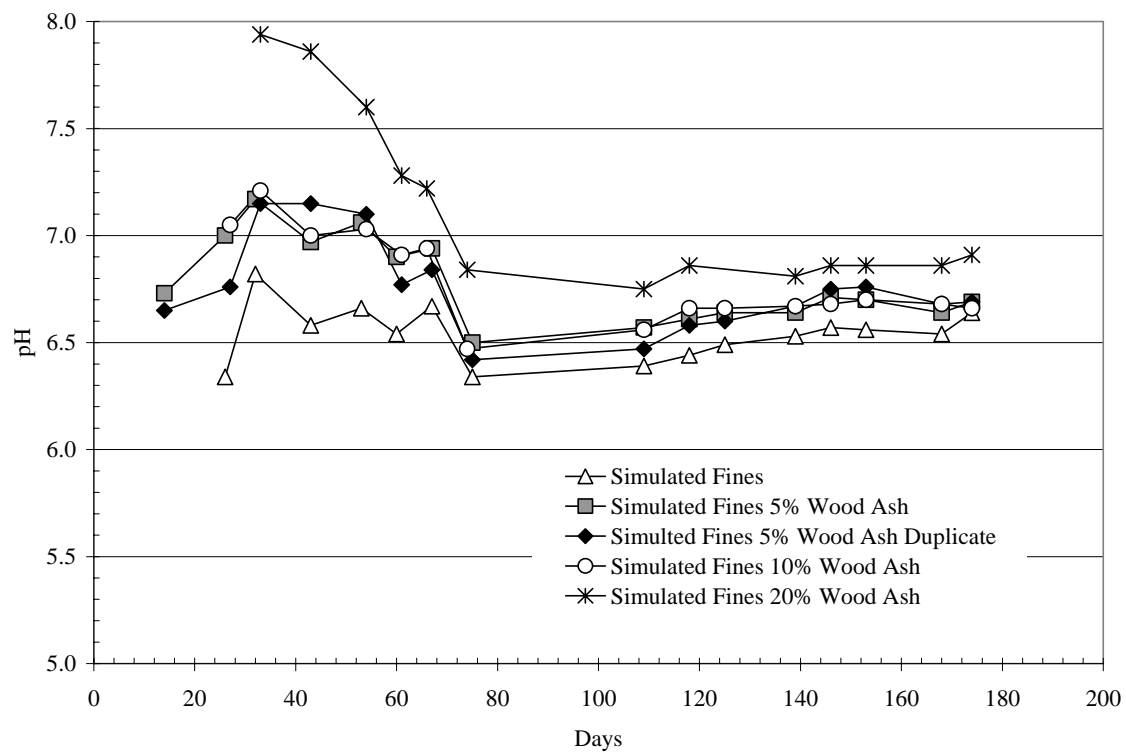
- DO Meter- Steady State Polarographic Probe
Range 0-20mg/L
Accuracy +/- 2% of reading or .2mg/L which ever is greater
Range 20-50mg/L
Accuracy +/- 6% of reading
- Temperature- YSI Precision® Thermistor
Range -5⁰-45⁰C
Accuracy +/- .15⁰C
- Conductivity-4 Electrode Cell with Auto Ranging
Range 0-200 mS/cm
Accuracy +/- .5% of reading or .001 mS/cm which ever is greater
- pH- Glass Combo Electrode
Range 0-14 units
Accuracy +/- .2 units
- ORP-Platinum Bottom Probe
Range -999-999 mV
Accuracy +/- 20mV

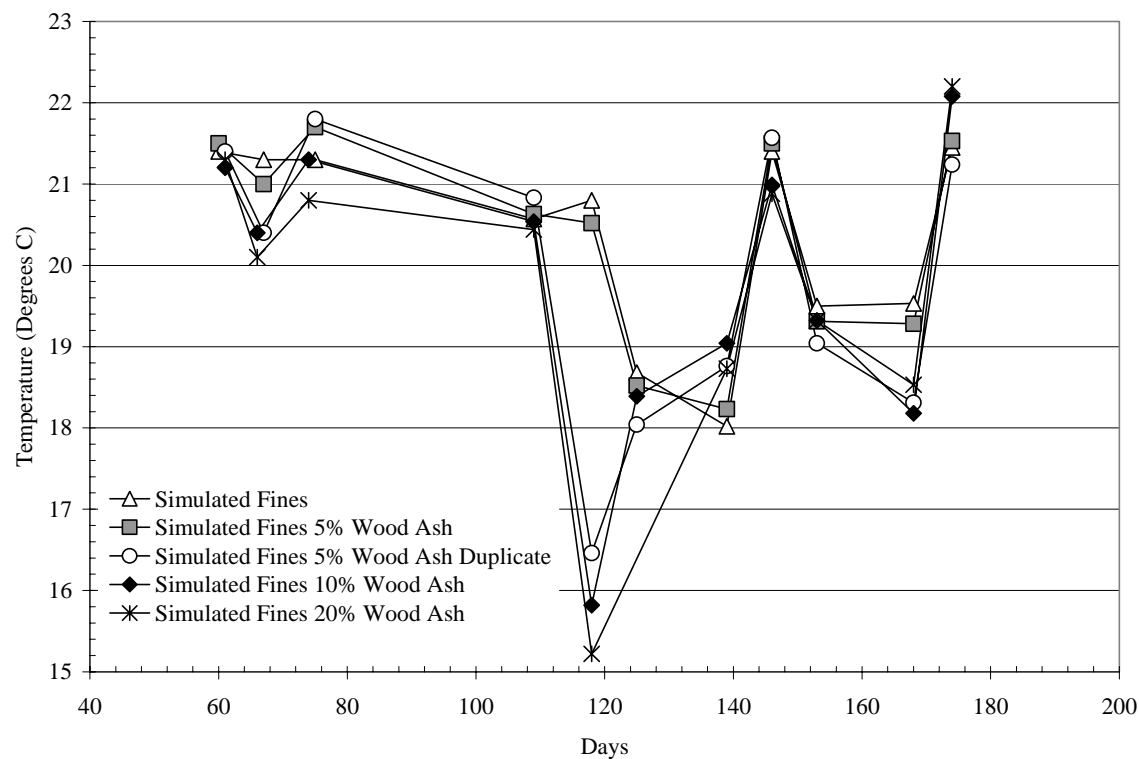
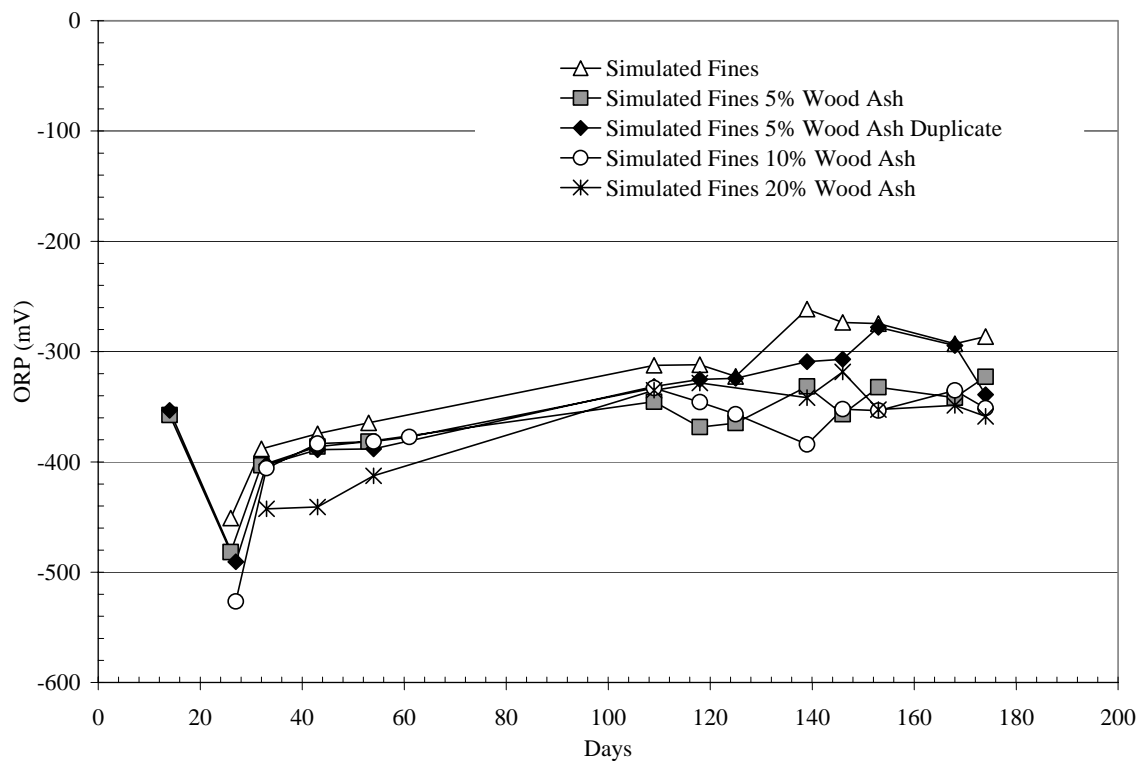
Appendix D. Leachate Results – Graphs and Tables

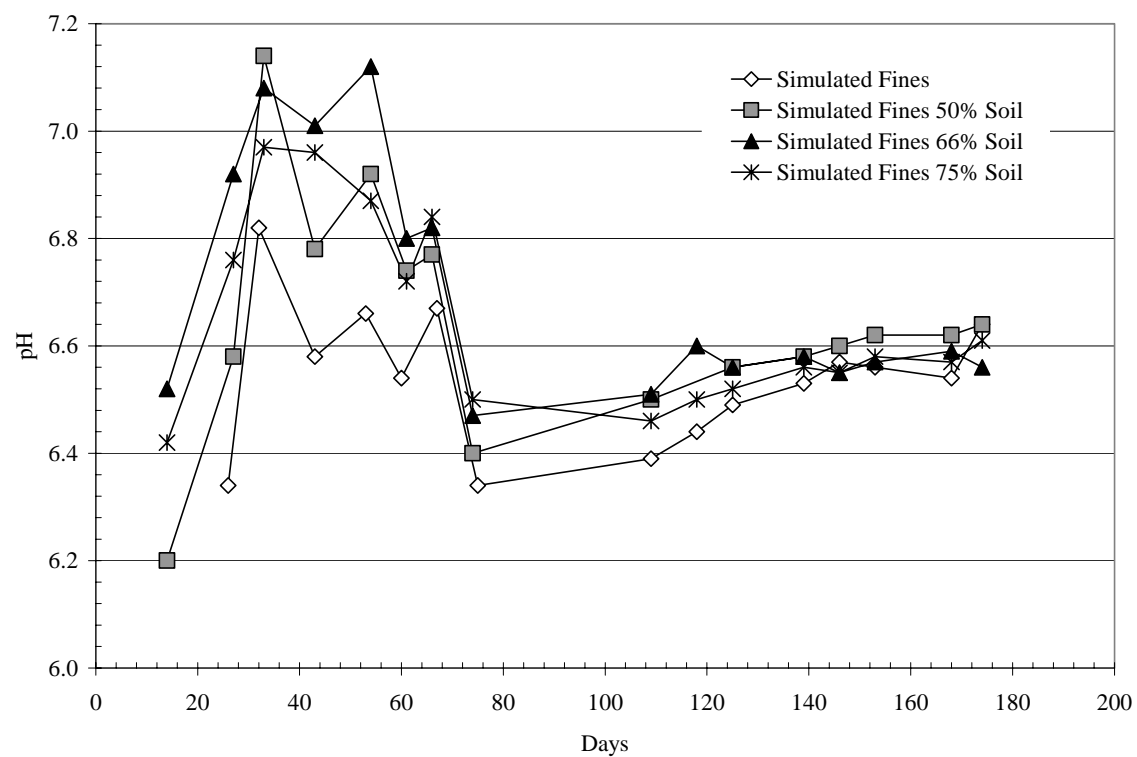
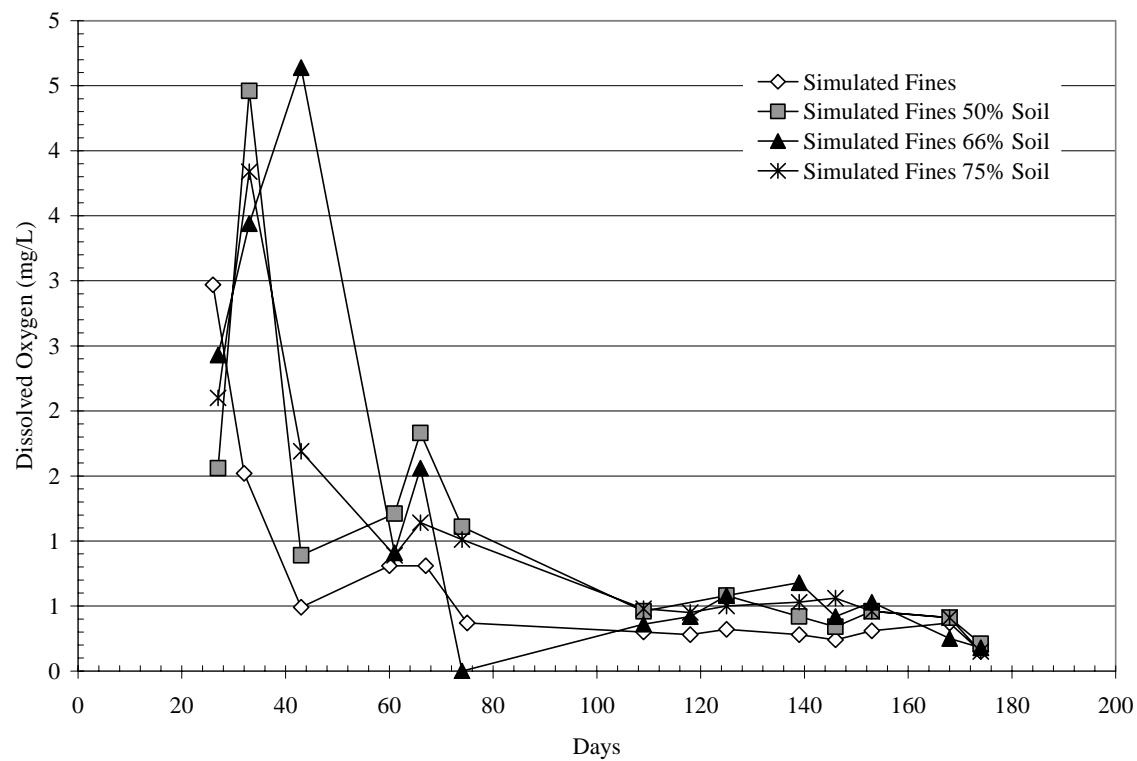


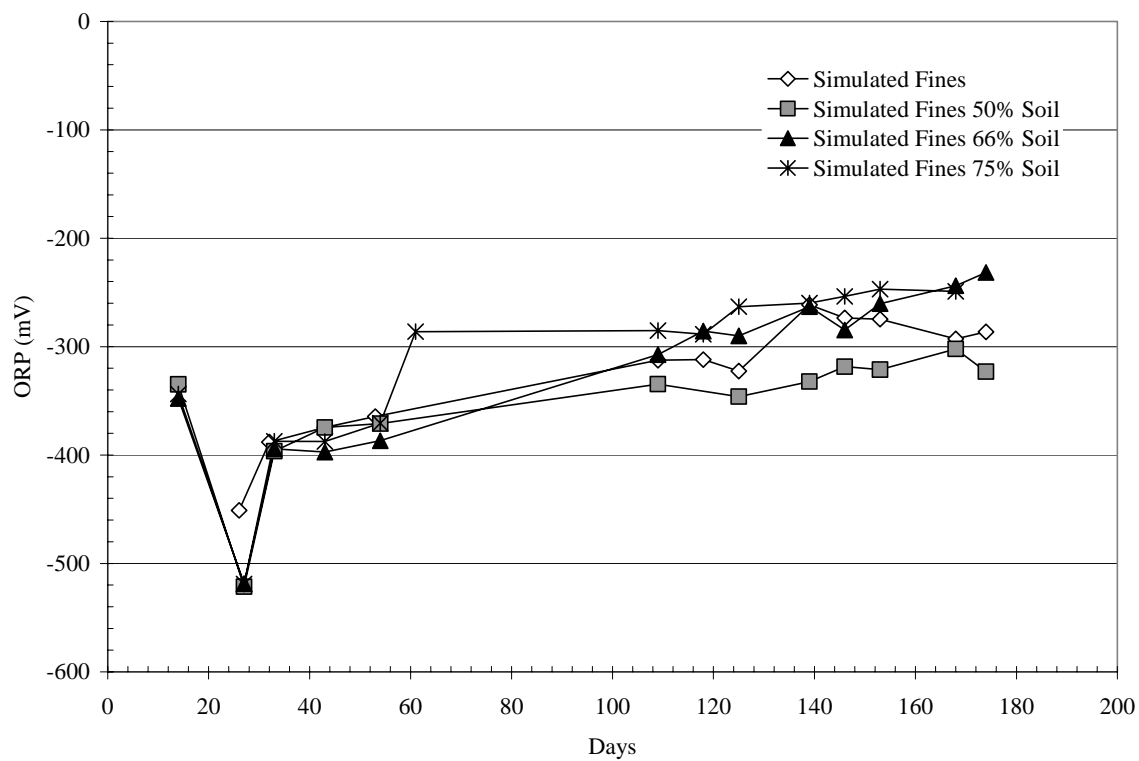
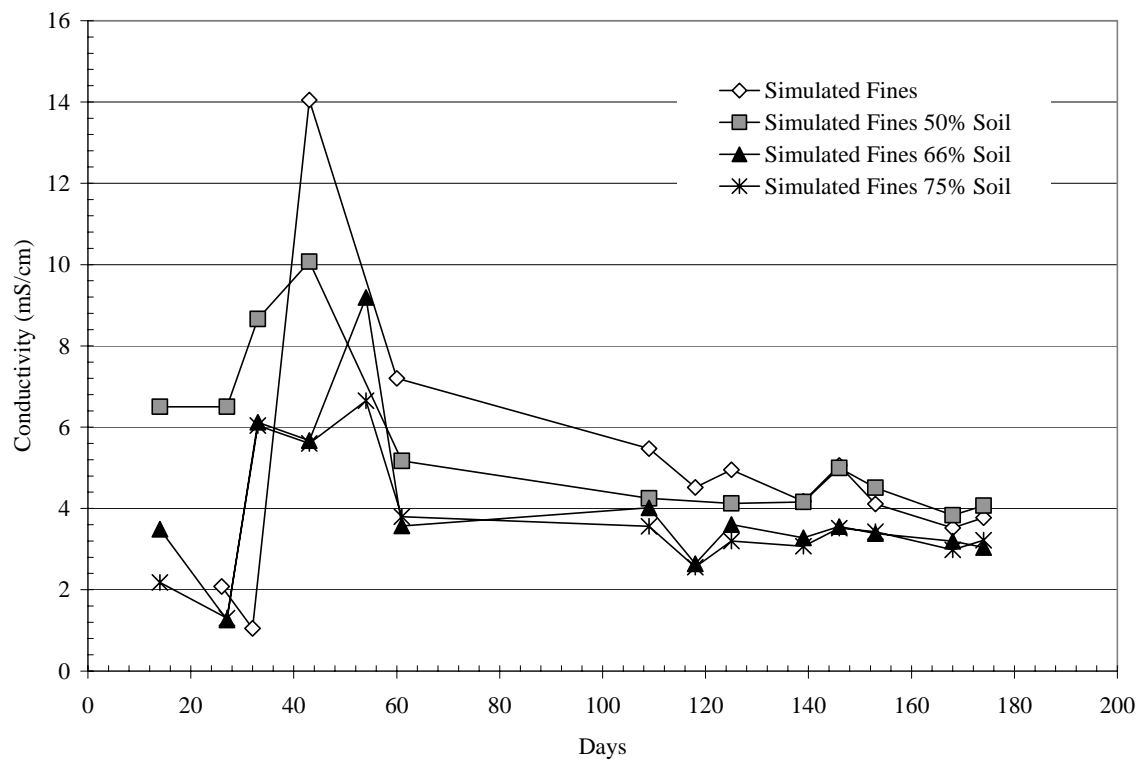


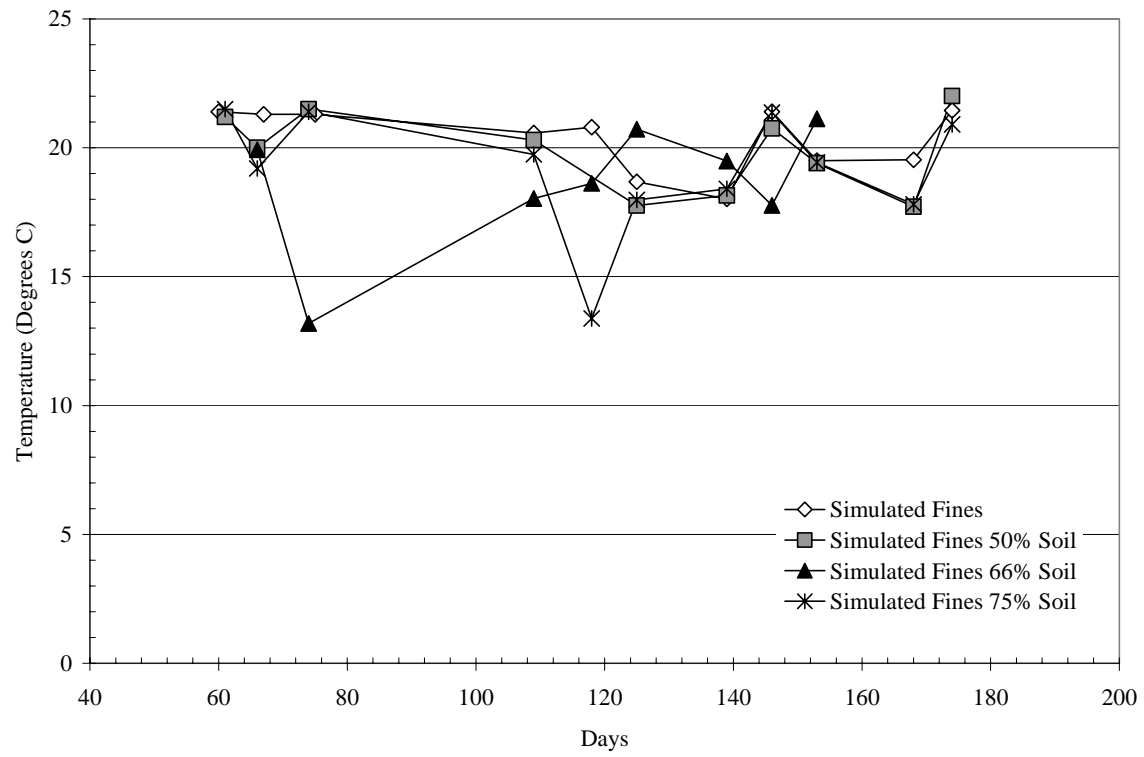












WMMA C&D Waste Fines								
Days	Volume of Leachate Drained (ml)	DO (mg/L)	pH	Conductivity (mS/cm)	ORP (mV)	Temp (°C)	Sulfate (mg/L)	Sulfide (mg/L)
14	N/A	N/A		N/A	N/A	N/A	1900	N/A
26	575	0.10	6.44	14.080	-412	N/A	1800	N/A
32	350	0.38	6.39	2.800	-382	N/A	1600	N/A
41	500	0.81	6.29	N/A	-362	N/A	1500	N/A
53	450	N/A	6.35	N/A	-352	N/A	1400	N/A
60	500	1.15	6.26	12.290	N/A	21.7	1300	N/A
68	500	1.07	6.28	10.990	-15.5	22.2	1300*	N/A
75	500	0.42	5.90	0.000	0.0	21.9	1300*	0.31
109	570	0.85	5.91	11.610	-134	21.0	1200*	0.01
118	345	0.42	6.01	11.740	-89.0	21.5	1100	0.26
125	430	0.69	6.02	11.250	-104	19.6	1200	0.29
132	400	1.01	6.01	8.170	-65.8	14.2	1100	0.28
139	470	0.73	6.05	8.637	-97.3	20.4	**	0.41
146	480	0.40	6.06	11.400	-149	21.6	**	1.06
153	445	0.90	6.05	8.370	-107	20.1	**	0.00
168	540	0.68	6.02	6.041	-96.3	0.0	**	2.08
174	300	0.33	6.09	9.763	-150	21.8	**	4.17
Min	0	0.1	5.90	0	-412	0	1100	0
Max	575	1.15	6.44	14.1	0	22.2	1900	4.17
Average	433	0.663	6.13	9.08	-157.2	18.8	1392	0.81

Note: N/A=sample result not available

*Sample analyzed after 28 day expiration period

**Result pending

WMMA C&D Waste Fines Duplicate								
Days	Volume of Leachate Drained (ml)	DO (mg/L)	pH	Conductivity (mS/cm)	ORP (mV)	Temp (°C)	Sulfate (mg/L)	Sulfide (mg/L)
14	N/A	N/A	6.38	96.8	-342	N/A	1800	N/A
26	500	0.18	6.70	4.19	-446	N/A	1800	N/A
32	400	0.37	6.81	6.10	-393	N/A	N/A	N/A
41	700	1.81	6.58	19.2	-362	N/A	N/A	N/A
53	350	N/A	6.84	N/A	-376	N/A	1400	N/A
60	800	0.89	6.51	10.9	N/A	21.7	1300	N/A
68	500	1.01	6.55	10.2	-15.5	22.3	N/A	N/A
75	400	0.27	6.15	N/A	N/A	21.9	1200*	0.45
109	510	0.78	6.20	10.6	-158	20.4	1200*	Non Detect
118	365	0.43	6.52	10.2	-142	20.9	1100	0.58
125	195	0.63	6.33	9.43	-118	18.3	1100	0.10
132	0	N/A	N/A	N/A	N/A	N/A	N/A	N/A
139	550	0.74	6.31	7.78	-131	19.7	**	7.70
146	800	0.35	6.32	10.4	-129	21.6	**	4.40
153	505	0.55	6.33	8.90	-134	19.6	**	N/A
168	800	0.39	6.31	6.87	-122	20.8	**	3.50
174	305	0.31	6.37	8.96	-151	21.7	**	4.95
Min	0	0.18	6.15	4.19	-446	18.32	1100	0.004
Max	800	1.81	6.84	96.8	-15.5	22.3	1800	7.70
Average	452	0.62	6.45	15.8	-216	20.8	1362	2.71

Note: N/A=sample result not available

*Sample analyzed after 28 day expiration period

**Result pending

WMMA C&D Waste Residuals								
Days	Volume of Leachate Drained (ml)	DO (mg/L)	pH	Conductivity (mS/cm)	ORP (mV)	Temp (°C)	Sulfate (mg/L)	Sulfide (mg/L)
14	115	N/A	6.13	3.35	-332	N/A	810	N/A
26	500	0.68	6.50	3.34	-454	N/A	350	N/A
32	550	2.11	6.54	1.09	-374	N/A	170	N/A
41	200	4.21	6.57	3.12	-361	N/A	92	N/A
53	300	N/A	6.48	4.86	-353	N/A	120	N/A
60	225	2.05	6.37	3.05	N/A	21.4	70	N/A
67	300	0.61	6.71	N/A	N/A	N/A	<5.0*	N/A
75	300	0.42	6.49	N/A	N/A	21.8	0.8*	0.25
109	365	0.65	6.63	4.30	-188	20.3	<5.0*	0.12
118	500	0.25	6.52	5.67	-313	20.8	10	0.64
125	360	0.55	6.44	2.41	-167	18.5	9	1.60
132	315	1.46	6.51	2.32	-136	12.9	13	1.10
139	450	0.63	6.37	1.84	-159	16.4	**	1.30
146	530	0.72	6.37	2.33	-178	21.4	**	N/A
153	480	0.66	6.45	2.54	-167	19.3	**	N/A
168	580	0.66	6.47	2.45	-245	21.0	**	10.1
174	400	0.49	6.43	2.40	-170	21.5	**	5.92
Min	0	0.25	6.13	1.09	-454	12.9	<5.0	0.12
Max	580	4.21	6.71	5.67	-136	21.8	810	10.1
Average	359	1.08	6.47	3.00	-257	19.6	138	2.63

Note: N/A=sample result not available

*Sample analyzed after 28 day expiration period

**Result pending

Other Facility C&D Waste Fines								
Days	Volume of Leachate Drained (ml)	DO (mg/L)	pH	Conductivity (mS/cm)	ORP (mV)	Temp (°C)	Sulfate (mg/L)	Sulfide (mg/L)
26	300	0.16	6.71	5.10	-462	N/A	2000	N/A
32	350	0.24	6.63	1.13	-381	N/A	1700	N/A
43	475	0.48	6.54	0.58	-376	N/A	1500	N/A
53	350	N/A	6.76	2.37	-360	N/A	1500	N/A
60	400	0.59	6.73	9.56	N/A	21.6	1000	N/A
67	450	0.66	6.68	N/A	N/A	22.1	<5.0*	N/A
75	400	0.57	6.33	N/A	N/A	21.4	<5.0*	2.00
109	570	0.30	6.55	5.15	-315	20.2	190*	0.43
118	400	0.26	6.56	5.64	-319	20.9	1300	67.8
125	245	0.20	6.55	5.86	-308	18.7	1500	35.2
132	415	0.51	6.56	4.75	-263	13.1	1500	78.8
139	585	0.28	6.58	5.03	-250	17.9	**	33.8
146	445	0.28	6.63	6.58	-258	21.5	**	45.1
153	480	0.29	6.61	6.15	-280	19.5	**	N/A
168	540	0.39	6.60	5.39	-331	20.2	**	45.6
174	0	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Min	0	0.16	6.33	0.58	-462	13.1	<5.0	0.43
Max	585	0.66	6.76	9.56	-250	22.1	2000	78.8
Average	377	0.37	6.60	4.87	-325	19.7	1109	38.6

Note: N/A=sample result not available

*Sample analyzed after 28 day expiration period

**Result pending

Simulated Fines								
Days	Volume of Leachate Drained (ml)	DO (mg/L)	pH	Conductivity (mS/cm)	ORP (mV)	Temp (°C)	Sulfate (mg/L)	Sulfide (mg/L)
26	650	2.97	6.34	2.08	-451	N/A	1100	N/A
32	550	1.52	6.82	1.05	-388	N/A	870	N/A
43	400	0.49	6.58	14.05	-375	N/A	730	N/A
53	400	N/A	6.66	N/A	-365	N/A	480	N/A
60	400	0.81	6.54	7.20	N/A	21.4	450	N/A
67	400	0.81	6.67	N/A	N/A	21.3	420*	N/A
75	400	0.37	6.34	N/A	N/A	21.3	390*	4.16
109	540	0.30	6.39	5.47	-313	20.6	<5.0*	0.52
118	500	0.28	6.44	4.52	-312	20.8	12	56.0
125	420	0.32	6.49	4.95	-323	18.7	31	37.8
132	0	N/A	N/A	N/A	N/A	N/A	N/A	N/A
139	525	0.28	6.53	4.18	-262	18.0	**	43.2
146	400	0.24	6.57	5.06	-274	21.4	**	44.1
153	550	0.31	6.56	4.11	-275	19.5	**	N/A
168	520	0.37	6.54	3.52	293	19.5	**	61.2
174	390	0.15	6.64	3.77	-286	21.5	**	78.4
Min	0	0.15	6.34	1.05	-451	18.0	<5.0	0.52
Max	650	2.97	6.82	14.1	293	21.5	1100	78.4
Average	440	0.66	6.54	5.00	-277	20.4	498	40.7

Note: N/A=sample result not available

*Sample analyzed after 28 day expiration period

**Result pending

Simulated Fines 5% Wood Ash								
Days	Volume of Leachate Drained (ml)	DO (mg/L)	pH	Conductivity (mS/cm)	ORP (mV)	Temp (°C)	Sulfate (mg/L)	Sulfide (mg/L)
14	65	N/A	6.73	164.30	-357.4	N/A	2000	N/A
20	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
26	550	0.83	7.00	70.80	-481.7	N/A	1600	N/A
32	600	0.81	7.17	14.17	-403.1	N/A	1100	N/A
43	475	1.18	6.97	11.12	-386.2	N/A	900	N/A
53	475	N/A	7.06	N/A	-381.6	N/A	760	N/A
60	400	1.03	6.90	6.36	N/A	21.5	650	N/A
67	450	N/A	6.94	N/A	N/A	21.0	610*	N/A
75	450	0.43	6.50	N/A	N/A	21.7	790*	0.45
109	470	0.86	6.57	5.21	-345.5	20.6	100*	238
118	385	0.26	6.61	5.27	-368.5	20.5	280	236
125	405	0.94	6.64	5.25	-364.7	18.5	120	145
132	0	N/A	N/A	N/A	N/A	N/A	N/A	N/A
139	545	0.46	6.64	4.73	-331.6	18.2	**	252
146	500	0.40	6.71	5.42	-356.7	21.5	**	238
153	415	0.50	6.70	5.13	-332.3	19.3	**	N/A
168	520	0.64	6.64	4.32	-341.8	19.3	**	275
174	325	0.48	6.69	4.74	-322.9	21.5	**	302
Min	0	0.26	6.5	4.32	-482	18.2	100	0.45
Max	600	1.18	7.17	164	-323	21.7	2000	302
Average	391	0.68	6.78	23.6	-367	20.3	810	210

Note: N/A=sample result not available

*Sample analyzed after 28 day expiration period

**Result pending

Simulated Fines 5% Wood Ash Duplicate								
Days	Volume of Leachate Drained (ml)	DO (mg/L)	pH	Conductivity (mS/cm)	ORP (mV)	Temp (°C)	Sulfate (mg/L)	Sulfide (mg/L)
14	85	N/A	6.65	22.40	-353.2	N/A	1700	N/A
27	1000	1.62	6.76	9.66	-490.6	N/A	1400	N/A
33	600	1.07	7.15	30.30	-402.6	N/A	1200	N/A
43	500	1.02	7.15	12.75	-388.9	N/A	800	N/A
54	475	N/A	7.10	N/A	-388.1	N/A	540	N/A
61	400	1.10	6.77	7.56	N/A	21.4	480	N/A
67	400	1.89	6.84	N/A	N/A	20.4	420 *	N/A
75	360	1.26	6.42	N/A	N/A	21.8	180 *	134
109	575	0.51	6.47	6.29	-331.5	20.8	<5.0 *	99.0
118	370	0.39	6.58	5.15	-325.1	16.5	61	91.5
125	220	0.46	6.60	4.91	-324.2	18.0	330	60.0
132	0	N/A	N/A	N/A	N/A	N/A	N/A	N/A
139	560	0.42	6.67	4.76	-309.2	18.8	**	61.0
146	445	0.50	6.75	5.09	-306.9	21.6	**	73.0
153	370	0.45	6.76	4.34	-278.0	19.0	**	N/A
168	600	0.57	6.68	3.71	-294.5	18.3	**	90.5
174	475	0.49	6.69	3.87	-339.1	21.2	**	166
Min	0	0.39	6.42	3.71	-490.6	16.5	<5.0	60.0
Max	1000	1.89	7.15	30.3	-278.00	21.8	1700	166
Average	413	0.84	6.75	9.29	-348.6	19.8	711	96.8

Note: N/A=sample result not available

*Sample analyzed after 28 day expiration period

**Result pending

Simulated Fines 10% Wood Ash								
Days	Volume of Leachate Drained (ml)	DO (mg/L)	pH	Conductivity (mS/cm)	ORP (mV)	Temp (°C)	Sulfate (mg/L)	Sulfide (mg/L)
27	400	1.68	7.05	18.75	-526	N/A	N/A	N/A
33	400	1.91	7.21	N/A	-406	N/A	N/A	N/A
43	500	1.37	7.00	288.10	-383	N/A	1800	N/A
54	450	N/A	7.03	N/A	-382	N/A	1500	N/A
61	375	1.40	6.91	10.76	-377	21.2	1600	N/A
66	400	2.26	6.94	N/A	N/A	20.4	1600*	N/A
74	470	1.55	6.47	N/A	N/A	21.3	1400*	104
109	345	1.44	6.56	9.85	-333	20.5	1000*	187
118	355	0.63	6.66	7.46	-346	15.8	910	290
125	470	0.98	6.66	7.77	-357	18.4	1000	256
132	0	N/A	N/A	N/A	N/A	N/A	N/A	N/A
139	590	0.67	6.67	7.02	-384	19.0	**	269
146	440	0.78	6.68	7.83	-352	21.0	**	270
153	415	0.70	6.70	7.22	-354	19.3	**	N/A
168	550	0.84	6.68	6.23	-335	18.2	**	359
174	360	0.64	6.66	6.42	-351	22.1	**	309
Min	0	0.63	6.47	6.23	-526	15.8	910	104
Max	590	2.26	7.21	288	-333	22.1	1800	359
Average	384	1.20	6.79	34.3	-376	19.8	1351	255

Note: N/A=sample result not available

*Sample analyzed after 28 day expiration period

**Result pending

Simulated Fines 20% Wood Ash								
Days	Volume of Leachate Drained (ml)	DO (mg/L)	pH	Conductivity (mS/cm)	ORP (mV)	Temp (°C)	Sulfate (mg/L)	Sulfide (mg/L)
27	0	N/A	N/A	N/A	N/A	N/A	N/A	N/A
33	300	2.57	7.94	>13.1	-443	N/A	N/A	N/A
43	450	0.68	7.86	N/A	-441	N/A	N/A	N/A
54	350	N/A	7.60	N/A	-413	N/A	3400	N/A
61	375	1.52	7.28	13.10	N/A	21.3	2800	N/A
66	475	1.59	7.22	N/A	N/A	20.1	2600*	N/A
74	450	1.29	6.84	N/A	N/A	20.8	N/A	42.0
109	500	0.81	6.75	12.96	-335	20.4	1900*	91.0
118	500	0.95	6.86	10.31	-329	15.2	2600	127
125	0	N/A	N/A	N/A	N/A	N/A	N/A	N/A
132	0	N/A	N/A	N/A	N/A	N/A	N/A	N/A
139	545	0.39	6.81	11.57	-342	18.7	**	127
146	370	0.55	6.86	12.84	-319	20.9	**	141
153	450	0.63	6.86	11.61	-353	19.3	**	N/A
168	600	0.61	6.86	9.92	-349	18.5	**	230
174	320	0.41	6.91	10.03	-359	22.2	**	215
Min	0	0.39	6.75	9.92	-443	15.2	1900	42.00
Max	600	2.57	7.94	13.1	-318.5	22.2	3400	230
Average	334	1.00	7.13	11.5	-368	19.8	2660	138.7

Note: N/A=sample result not available

*Sample analyzed after 28 day expiration period

**Result pending

Simulated Fines 50% Soil								
Days	Volume of Leachate Drained (ml)	DO(mg/L)	pH	Conductivity (mS/cm)	ORP (mV)	Temp (°C)	Sulfate (mg/L)	Sulfide (mg/L)
14	500	N/A	6.20	6.50	-335	N/A	1500	N/A
27	1100	1.56	6.58	6.50	-521	N/A	1100	N/A
33	200	4.46	7.14	8.66	-396	N/A	970	N/A
43	475	0.89	6.78	10.07	-375	N/A	830	N/A
54	400	N/A	6.92	N/A	-371	N/A	650	N/A
61	300	1.21	6.74	5.17	N/A	21.2	550	N/A
66	500	1.83	6.77	N/A	N/A	20.0	580*	N/A
74	425	1.11	6.40	N/A	N/A	21.5	1200*	68.0
109	665	0.46	6.50	4.25	-335	20.3	5.6*	116
118	0	N/A	N/A	N/A	N/A	N/A	N/A	N/A
125	555	0.58	6.56	4.13	-346	17.8	160	111
132	0	N/A	N/A	N/A	N/A	N/A	N/A	N/A
139	660	0.42	6.58	4.16	-332	18.2	**	192
146	360	0.34	6.60	5.00	-319	20.8	**	148
153	485	0.46	6.62	4.51	-321	19.4	**	N/A
168	580	0.41	6.62	3.83	-302	17.7	**	180
174	405	0.21	6.64	4.07	-323	22.0	**	111
Min	0	0.21	6.2	3.83	-521	17.7	5.6	68.0
Max	1100	4.46	7.14	10.1	-302	22.0	1500	192
Average	423	1.07	6.64	5.57	-356	19.9	754	132

Note: N/A=sample result not available

*Sample analyzed after 28 day expiration period

**Result pending

Simulated Fines 66% Soil								
Days	Volume of Leachate Drained (ml)	DO(mg/L)	pH	Conductivity (mS/cm)	ORP (mV)	Temp (°C)	Sulfate (mg/L)	Sulfide (mg/L)
14	800	N/A	6.52	3.49	-347.9	N/A	1500	N/A
27	1200	2.43	6.92	1.26	-518.7	N/A	1000	N/A
33	400	3.44	7.08	6.12	-394.2	N/A	890	N/A
43	750	4.64	7.01	5.67	-397.3	N/A	630	N/A
54	450	N/A	7.12	9.19	-386.9	N/A	420	N/A
61	300	0.91	6.80	3.57	N\A	21.3	360	N/A
66	450	1.56	6.82	N/A	N\A	19.1	380*	N/A
74	450	1.1.2	6.47	N/A	N\A	21.6	340*	7.20
109	585	0.36	6.51	4.02	-307.4	19.9	390*	19.5
118	350	0.42	6.60	2.64	-285.7	13.2	680	11.5
125	405	0.58	6.56	3.61	-290.0	18.0	430	15.5
132	0	N/A	N/A	N/A	N\A	N/A	N/A	N/A
139	630	0.68	6.58	3.28	-263.2	18.6	**	41.5
146	530	0.42	6.55	3.56	-284.7	20.7	**	17.0
153	355	0.53	6.57	3.38	-260.3	19.5	**	N/A
168	565	0.25	6.59	3.19	-243.8	17.8	**	14.0
174	405	0.18	6.56	3.04	-231.6	21.1	**	17.5
Min	0	0.18	6.47	1.26	-518.7	13.2	340	7.2
Max	1200	4.64	7.12	9.19	-231.6	21.6	1500	41.5
Average	479	1.26	6.7	4.00	-324	19.2	638	17.96

Note: N/A=sample result not available

*Sample analyzed after 28 day expiration period

**Result pending

Simulated Fines 75% Soil								
Days	Volume of Leachate Drained (ml)	DO (mg/L)	pH	Conductivity (mS/cm)	ORP (mV)	Temp (°C)	Sulfate (mg/L)	Sulfide (mg/L)
14	1200	N/A	6.42	2.18	-344	N/A	1500	N/A
27	1150	2.10	6.76	1.30	-519	N/A	630	N/A
33	625	3.84	6.97	6.04	-387	N/A	N/A	N/A
43	600	1.69	6.96	5.60	-388	N/A	240	N/A
54	500	N/A	6.87	6.65	-371	N/A	100	N/A
61	350	0.89	6.72	3.80	N/A	21.5	41	N/A
66	500	1.14	6.84	N/A	N/A	19.2	53*	N/A
74	400	1.01	6.50	N/A	N/A	21.4	53*	29.2
109	690	0.48	6.46	3.56	-286	19.7	37*	3.00
118	425	0.45	6.50	2.56	-285	13.4	50	10.0
125	420	0.50	6.52	3.20	-289	18.0	160	29.0
132	0	N/A	N/A	N/A	N/A	N/A	N/A	N/A
139	560	0.53	6.56	3.07	-263	18.4	**	23.0
146	505	0.56	6.55	3.52	-260	21.4	**	38.5
153	395	0.46	6.58	3.43	-254	19.4	**	N/A
168	635	0.41	6.57	2.98	-247	17.8	**	6.00
174	305	0.15	6.61	3.22	-249	20.9	**	16.5
Min	0	0.15	6.42	1.3	-519	13.38	37	3.00
Max	1200	3.84	6.97	6.65	-247	21.5	1500	38.5
Average	514	1.02	6.65	3.65	-319	19.2	286	19.4

Note: N/A=sample result not available

*Sample analyzed after 28 day expiration period

**Result pending